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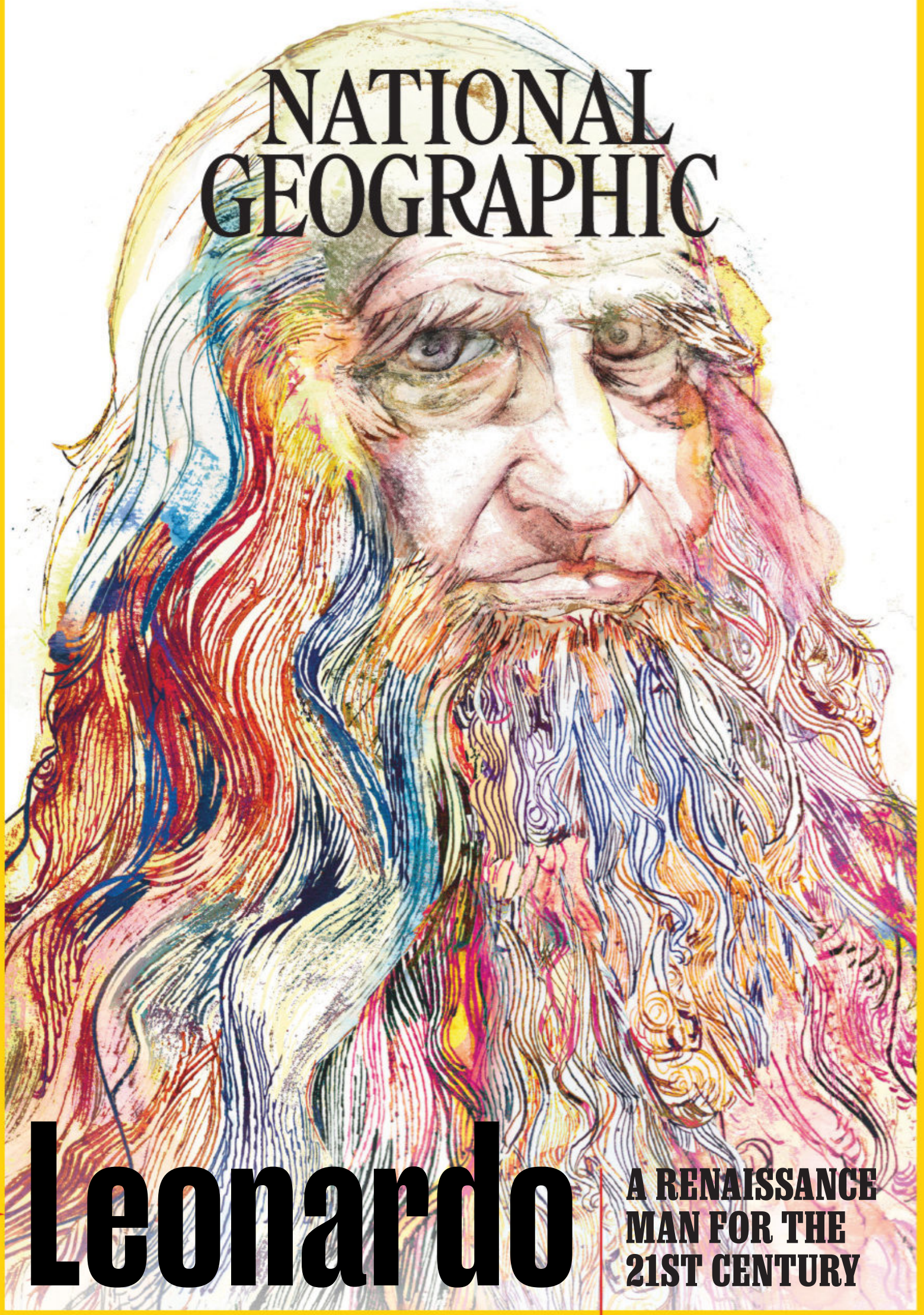

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On the Cover
The 500th anniversary of Leonardo da Vinci's death is bringing renewed attention to his notebooks—and the artistry, curiosity, and genius they contain.
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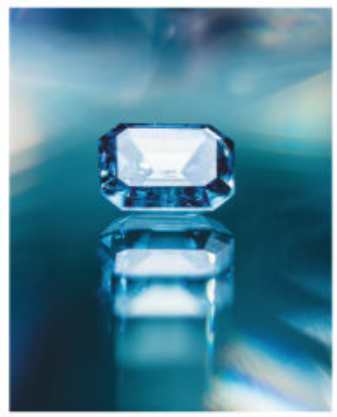

EXPLORE

FEATURES

NAT GEO TV

Scientists Confront a Lethal Foe in *The Hot Zone*

Richard Preston's best-selling book *The Hot Zone* tells the story of the origins of the deadly Ebola virus in the central African rainforest and its arrival on U.S. soil in 1989. Now the book is a television miniseries in which Nancy Jaax, the heroic U.S. Army scientist who helped prevent the virus's spread, is played by Julianna Margulies (above, at right). The six-part series will air two episodes a night starting at 9/8c, on May 27, 28, and 29 on National Geographic.

TELEVISION

This Is Not Your High School's *Science Fair*

Each year 1,700 teen scientists are invited to compete in the International Science and Engineering Fair, where more than four million dollars in scholarships and awards are at stake. Go inside the event with the documentary *Science Fair,* airing on May 9 at 8/7c on National Geographic.

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PLANET **OR** PLASTIC?

Oceans of Debris

BY **SUSAN GOLDBERG** PHOTOGRAPH BY **DAVID LIITTSCHWAGER**

One net off the coast of Hawaii collected 2,459 plastic particles—most the size of a grain of sand. The net also scooped up a bottle cap (bottom right) and a wad of degraded fishing net (top right).

THERE'S THE PLASTIC waste we can see—bottles, bags, discarded fishing nets, and all manner of other objects littering shorelines and bobbing in oceans. And then there's the plastic waste we can't see: microplastics, whittled by sun, wind, and waves into bits so small that some are visible only under a microscope. Scientists are just beginning to understand the impact these particles are having on fish, the food chain, and ultimately, us.

For this month's story about microplastics—part of National Geographic's #PlanetOrPlastic initiative to reduce plastic waste—photographer David Liittschwager documented the ubiquity of plastics in ocean water samples. Writer Laura Parker's reporting took her to a National Oceanic and Atmospheric Administration lab in Honolulu, where oceanographer Jamison Gove and fish biologist Jonathan Whitney study microplastics in the slicks where larval fish spend their first days of life.

In some of those slicks there are more plastics in the water than fish. That raises the odds that just hatched fish will mistake plastic bits for food and eat them. "The most critical moment is that first feeding," Whitney said. "If they get a piece of plastic, that could be it. A single thread in the stomach of a larval fish is potentially a killer."

Fish that ingest plastic and survive raise other concerns, Parker writes: "Flying fish appear to eat plastic especially frequently. Besides serving as prey for larger fish, including sharks, flying fish are primary prey for 95 percent of Hawaiian seabirds. Are birds ingesting plastic with their flying fish, and is that affecting them? For every question the researchers answer, Gove says, 10 new ones come up."

Most of us won't see microplastics' harm at the level that scientists do. But with about nine million tons of visible plastic waste washing into oceans each year, we see clearly how it's hurting turtles, seabirds, whales, and many other species. Isn't that reason enough to join the global effort to reduce plastic waste?

So far in our #PlanetOrPlastic initiative, more than 150,000 people have pledged to use nearly 200 million fewer single-use plastic items. I'd call that a good start. ▯

Learn more about plastic waste and take the pledge to reduce it at ***natgeo.com/plasticpledge.***

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PHOTOGRAPHS BY **DANIEL OCHOA DE OLZA**

LOOKING AT THE EARTH FROM EVERY POSSIBLE ANGLE

MODERN GIRLS, ANCIENT RITE

In May a village in Spain welcomes spring the way it has for centuries, by featuring girls on altars.

VOL. 235 NO. 5

A young girl does her part to celebrate the festival of La Maya, which marks the arrival of spring in Colmenar Viejo, Spain.

La Maya, a tradition in central Spain for many years, has only a few written rules. Altars must be decorated with fresh flowers, and the young centerpieces must sit perfectly still for the two-hour observance.

Aspiring Mayas might have to wait a long time before they sit on an altar. Only about five are chosen each year. Festival officials keep a running list of local girls who may be eligible in the future.

Crowds pass through the village's streets for a glimpse of each altar. After the festival, the Mayas come down and attend evening Mass with the community.

THE BACKSTORY

A FEW LUCKY GIRLS IN A SPANISH VILLAGE BECOME SYMBOLS OF SPRING IN FLOWER FRAMES.

WHAT MAKES A TRADITION—and why do people keep traditions alive? You might ask any of the children chosen to be Las Mayas in Colmenar Viejo, a village in Spain. Each spring, a few girls typically between the ages of seven and 11 sit in elaborate altars decorated with fresh flowers to mark the new season.

As crowds pass by for two hours, the girls are to sit perfectly still, their facial expressions a sign of how seriously they take their roles. Families are honored if their daughter is selected from the dozens of young girls who apply to participate in this local tradition with ancient roots. But taking part means weeks of feverish activity preparing the elaborate altars and dresses.

Photographer Daniel Ochoa de Olza has spent his career documenting Spanish traditions, from the serious to the sublime. At each, he wonders why they continue. He recalls a festival in Piornal, Spain, where villagers pelt an armored, devil-like character with turnips. And there's the famous festival of San Fermín in Pamplona, Ochoa de Olza's hometown—the running of the bulls. "It's stupid and it's dangerous, but it's our tradition," he says, admitting that he's run nine times.

The Maya girls create the compositions in which they star, so the portraits aren't photographically daring, says Ochoa de Olza. But they're revelatory in the sense that, even in one's own country, there are always new customs to discover—practices with vibrancy and beauty, even if they may be fleeting.

The magic of being a Maya tends to fade as the girls grow beyond childhood, says Ochoa de Olza. As teenagers, onetime Mayas tend to laugh off their past participation, projecting cool by disavowing their youthful enthusiasm. And yet, as former Mayas have daughters of their own, the tradition continues. **—DANIEL STONE**

For one day, Mayas are the center of attention in their village. Passersby marvel at each altar.

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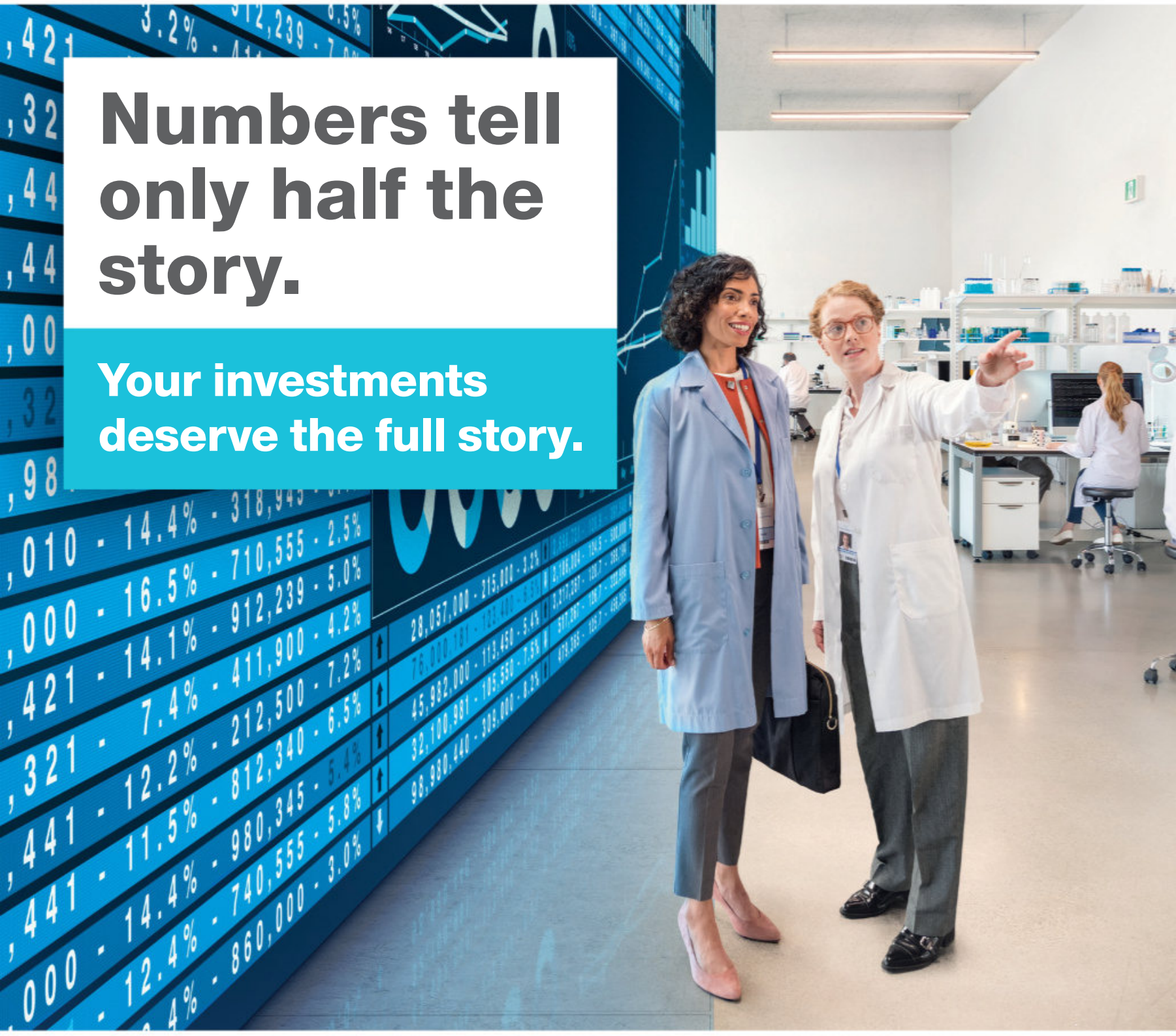

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THE DISCOVERIES OF TODAY THAT WILL DEFINE THE WORLD OF TOMORROW

NATIONAL GEOGRAPHIC | VOL. 234 NO. 5

The Future of Dying in Style

WE MEMORIALIZE THE DEAD WITH THE TOOLS OF OUR TIMES. IN THE HIGH-TECH 21ST CENTURY, THERE ARE SOME PRETTY ODD OPTIONS.

BY **GLENN McDONALD**

THROUGHOUT HISTORY, PEOPLE have devised elaborate ways to memorialize the dead: the pyramids of Egypt, Europe's Gothic mausoleums, the Taj Mahal in India. What some mourners consider meaningful, others would call macabre. In 19th-century Europe and America, "death photography" produced portraits of the departed in lifelike poses; in the Tibetan Buddhist rite known as sky burial or *bya gtor* (alms for the birds), earthly remains are set out to feed vultures.

Notions about honoring the dead are shaped by many factors—culture, tradition, geography, religion. But the notion is one thing, and the execution is another. In every era, it's the available technology that determines our range of memorial options.

The intersections of death and technology have long been busy crossroads. In these early years of the 21st century, they're getting really interesting. Because I write about science and technology for a living, I've lingered at these intersections,

USING HIGH-TECH MACHINES, ENGINEERS CAN TRANSFORM THE CARBON FROM HUMAN ASHES INTO DIAMOND GEMS THAT ARE PHYSICALLY AND CHEMICALLY IDENTICAL TO NATURAL DIAMONDS.

observing the innovations: digital memorials on social media, eco-friendly green burial options, even interactive tombstones.

Among the tech-savvy options for modern decedents, one stands out because it's so genuinely weird. Thanks to startling advances in industrial engineering, we can now synthetically re-create colossal geological forces to shape our ultimate destiny on this planet. It's gratuitous and extreme and wonderful: We can turn our mortal remains into diamonds. Real diamonds.

SEVERAL COMPANIES WORLDWIDE now offer services to families that have the notion, and the resources, to memorialize their loved ones in arguably the most permanent way possible. The Swiss company Algordanza is one of them.

Using high-tech heavy-industry machines, engineers can transform the carbon from human ashes into diamond gems that are physically and chemically identical to natural diamonds. The geologic process that otherwise takes hundreds of millions of years can now be managed in weeks.

It works like this: After the cremation, the bereaved family ships one pound of ashes to Algordanza's laboratory in Switzerland. Scientists process the ashes to extract the pure carbon elements and remove other impurities. (The remaining ashes are shipped back.) From there, Algordanza uses the same tools Mother Nature uses to make diamonds: heat and pressure.

In the next step, the carbon ashes are converted into graphite, a stable allotrope of carbon in which the atoms are packed into tight, flat sheets. Then the carbon settles down for a long bake inside Algordanza's high-pressure, high-temperature (HPHT) machines. Temperatures rise as high as about 2,400 degrees Fahrenheit. For comparison, consider that cast iron melts at about 2,200 degrees Fahrenheit.

Then there's the pressure. Within the HPHT machine, a system of cubic presses exerts a force of 870,000 pounds per square inch on the graphite, gradually changing the molecular structure and transforming the carbon into pure diamond.

To be clear, these diamonds aren't just similar to a natural diamond; they are identical down to the atomic level. The gem that emerges can be kept in its rough state or cut and polished by Algordanza's specialists.

The entire operation—from initial receipt of ashes to final delivery of the diamond—typically takes five to eight months. The company processes approximately 1,000 memorial diamonds a year and has representatives in 34 countries.

Ashes to Ashes: Other Options

Memorial diamonds (right) are just one of many contemporary options for processing cremation ashes.

Long live rock! A British company will press your loved one's ashes into a custom-made vinyl record. Puns provided at no extra cost: The company's name is And Vinyly (say it aloud).

Under the sea: Ocean lovers may want to make their afterlife plans with a Florida company that incorporates cremains into artificial reefs and marine habitats.

Space oddity: A Houston-based business has partnered with commercial spaceflight companies to send ashes into orbit, to the moon, or even into deep space. Heads up, though: The prices are, yes, astronomical.

CHRISTINA MARTOIA WAS 18 when her father died. Ten years later, she and her mother had his ashes transformed into this half-carat diamond. "Every time I show someone my memorial diamond, I get to talk about my dad," says Martoia, the U.S. representative of Algordanza, the company that makes the diamonds.

PHOTO: DAN WINTERS

Algordanza offers packages with prices starting at about $3,000, says Christina Martoia, its U.S. representative. About that pricing—perhaps it's impolite to ask, but we all want to know, right?

"The largest Algordanza memorial diamond produced to date was a 1.76-carat brilliant cut," Martoia says. "The price was $38,000."

WHILE THE HARD SCIENCE of memorial diamonds is fascinating—a billion years in a matter of weeks!—the price may be out of reach for us budget-minded afterlife planners. Death is already mandatory and largely unpleasant. Does it have to be expensive too?

Happily, another company has stepped into this odd little marketplace. Headquartered in Barcelona, the Spanish start-up Bios Urn offers a much more affordable high-tech memorial option.

By way of a smartphone app and a kind of interactive funeral urn, the Bios system lets grieving families turn their departed loved one into an indoor tree for their home. A capsule of cremains is bedded in a large pot, in which a seedling is planted. As the seedling grows, it sends roots into the cremains, and the Bios Incube automatically waters and cares for the memorial sapling. Built-in sensors monitor temperature, humidity, and soil conditions. Information beamed to the smartphone allows the family to nurture the sapling as it grows into a tree.

The company offers two versions. One provides the basic biodegradable urn and planter for $145. The more expensive version, incorporating the sensors and the app, is around $700. I could swing that, and I kind of like the idea of making my kids take care of me through my oaken golden years.

CANDI K. CANN is one of the world's leading experts on modern mourning. She teaches comparative religion at Baylor University in Texas and is the author of the book *Virtual Afterlives: Grieving the Dead in the Twenty-First Century*. She says that as a mourning custom, memorial diamonds and smart urns are really just modern iterations of much older cultural traditions. Both are associated with the psychological concept of continuing bonds.

The idea is that keeping the decedent in one's life, in some form, is healthier than the detachment of, for instance, putting Dad six feet under. The diamond or the urn reflects "the need for continued rituals that incorporate and acknowledge the role of the loss of the deceased person," Cann says. "It allows the living to grieve without being forced to 'move on' or forget the dead."

If you're interested in going down this particular rabbit hole, Cann suggests looking into the strange beauty of Victorian mourning jewelry. "The bereaved would take a lock of the decedent's hair and turn it into wearable and functional jewelry," she says. "Often the hair was woven into an intricate design and turned into a ring, a brooch, or a pin. Only the bereaved knew the origins of the hair."

Cann says such jewelry is meant to serve the same function as today's diamond or interactive urn—or yesteryear's death photography, for that matter. It's about people turning to the technology of their era to navigate death and dying. The Romans did it. The Persians did it. The Maya did it. We're doing it with delicate microchips and massive machines. The technologies change, but the basic human experience remains.

Since I have some time (I hope), I plan to postpone any decisions until I've surveyed all my 21st-century options. Right now I'm leaning toward the tree. It's more cheerful, and I've always admired the sedentary style of flora as a lifestyle choice.

Besides, that diamond thing seems like a lot of pressure. ▯

Glenn McDonald writes about science, technology, and culture from his home in Chapel Hill, North Carolina.

Will bytes replace gravestones?

A HISTORIAN ASKS HOW WE'LL MARK DEATH AND MEMORIALIZE LOVED ONES IN A DIGITAL FUTURE.

Katie Thornton has been thinking quite a bit about death. For the past few years, the cemetery historian has examined epitaphs and researched the "residents" buried at Lakewood Cemetery in her hometown of Minneapolis, with the goal of preserving stories for posterity. "A lot is at stake right now," says the Fulbright-National Geographic digital storytelling fellow. Around the world, people are questioning whether cemeteries are a sustainable use of scarce land. "Without planning, the stories buried at cemeteries could be lost forever," Thornton says—but technology may offer a solution. Thornton is launching a podcast, *Death in the Digital Age,* to explore how global urbanization and the rise of digital documentation are changing conventions for memorializing the dead, especially in England and Singapore. Thornton discusses her work on National Geographic's Open Explorer platform. **—ANNIE ROTH**

Learn more at *openexplorer.nationalgeographic.com*.

PHOTO: GARY BURKS, CITY OF LONDON CEMETERY AND CREMATORIUM

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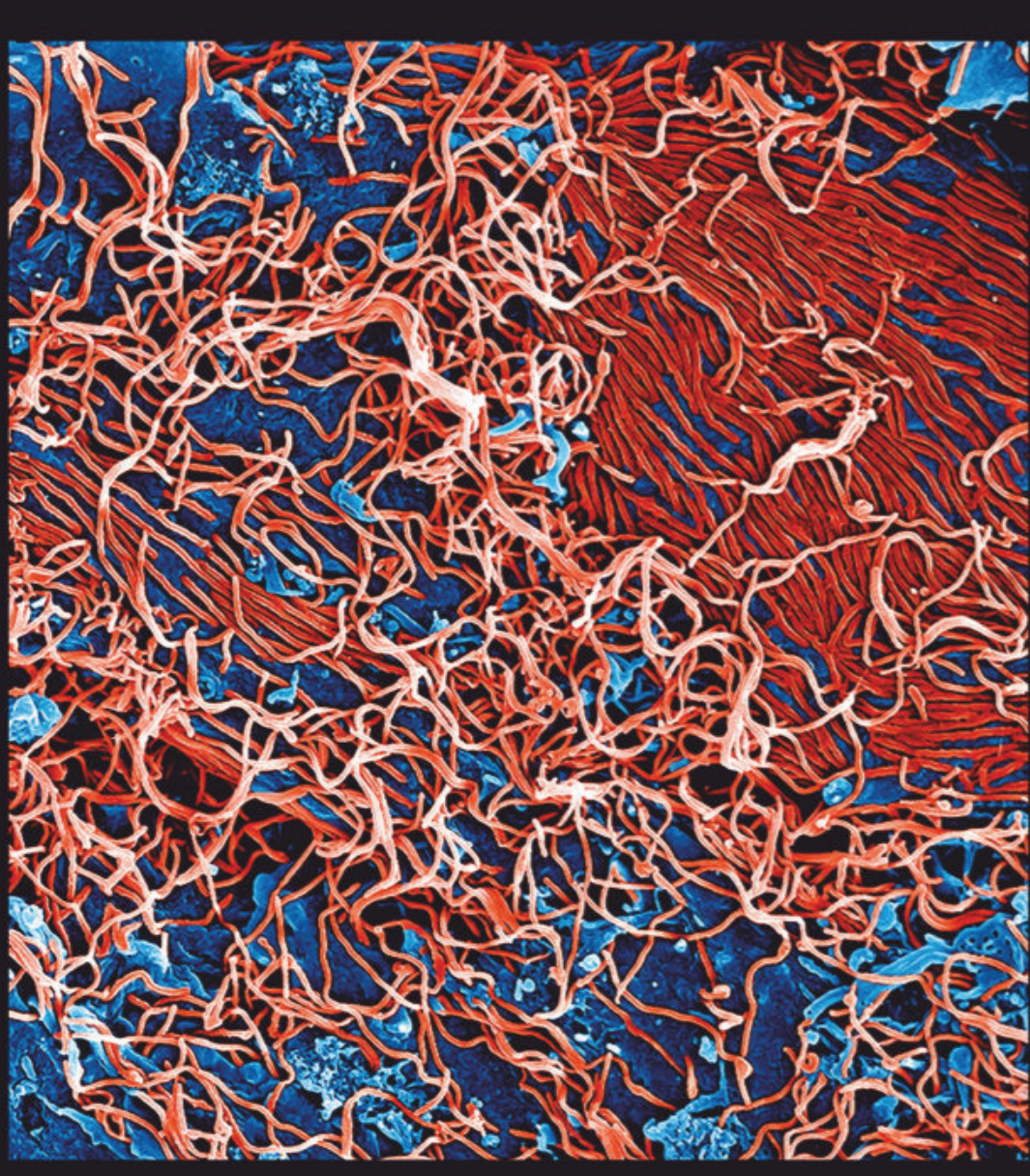
FOUR REASONS SCIENTISTS HAVEN'T YET STOPPED EBOLA

BY **RICHARD PRESTON**

IN THE 25 YEARS since my book *The Hot Zone* traced the emergence of extremely lethal viruses, one of them has proved to be the most destructive: Ebola. At this writing, Ebola has killed hundreds in the Democratic Republic of the Congo, in the second largest outbreak since the virus was identified in 1976. The largest—from 2014 to 2016 in three West African nations—resulted in almost 30,000 cases, nearly half of them fatal. Fierce international efforts helped quell Ebola that time, but there are no assurances that the virus (below) has ended its assaults on the human species. Ebola is hard to arrest for many complicated reasons (right). But scientists keep trying—and what they learn will equip us to face this virus, and possibly worse, in the future.



Why is Ebola so hard to fight?

1. THE VACCINE'S REQUIREMENTS

Ebola vaccine has to be kept cold. But in tropical areas where little refrigeration is available, the vaccine can quickly become useless. And we don't yet have a dried or otherwise nonperishable form of the vaccine.

2. CONSTRAINTS AND COSTS OF NEW DRUGS

There are experimental, genetically engineered drugs for Ebola, but it's not yet clear if they'll be broadly effective, and affordable enough that they'll be feasible for mass treatment of Ebola victims.

3. THE FAILURE OF A TECHNIQUE THAT STOPPED PAST VIRUSES

In 1966, during a large outbreak of smallpox virus, vaccinators tried a technique called ring vaccination with great success: They vaccinated people in a ring around the infected person. This trapped the virus inside a wall of immune people and stopped it from spreading. But attempts to use the technique with Ebola have run into problems. Ring vaccination requires a stable government or other authority maintaining civil order. The Ebola areas in the Democratic Republic of the Congo are controlled by violent militias that won't let vaccinators do their work.

4. GAPS IN SCIENTISTS' UNDERSTANDING OF HOW EBOLA KILLS

Ebola remains mysterious. It is unbelievably aggressive in the human body, but scientists still don't understand all the virus's mechanisms, and they aren't sure exactly how Ebola kills a human being. The great military strategist Sun Tzu said, "Know the enemy." We're still getting to know Ebola. When we finally do, we'll know the paths to defeat it. –RP

Watch *The Hot Zone*

Richard Preston's international best seller—inspired by the true story of Ebola's origins and first arrival on U.S. soil in 1989—is now a global miniseries. Two episodes of *The Hot Zone* will air each night on May 27, 28, and 29, starting at 9/8c, on National Geographic.

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Bee Backpacks

Researchers have created sensors small enough for bumblebees to wear and still fly. While the bees buzz around, the devices collect data such as humidity and temperature, which can be used to better understand plant and insect biology—and benefit agriculture. –DOUGLAS MAIN

SPACE

BRAINS IN SPACE

HUMAN BODIES WERE BUILT FOR GRAVITY. WE'RE STARTING TO UNDERSTAND HOW LIVING WITHOUT IT COULD MESS US UP.

OUR FLESHLY FORMS EVOLVED to work within the tug of gravity. Without it, the clockwork of bodily functions doesn't run smoothly. One recent study in the *New England Journal of Medicine* raises concern for a particularly vital organ: the brain. By scanning 10 cosmonauts' craniums before and after six months in space, scientists found that their gray matter—responsible for things like muscle control, memory, and sensory perception—became compressed by an increase in the cerebrospinal fluid that cushions it. Returning to Earth helped the gray matter mostly bounce back but seemed to cause shrinkage in white matter, which connects parts of the brain. More study is needed, but the find suggests life among the stars may be hard on Earthlings. –MAYA WEI-HAAS

FOOD

Secret Gardens

California gold rush–era mining sites hold hidden treasure: rare heirloom fruits and nuts. Scientists hope to learn from the mountain orchards, which have survived drought, diseases, and pests without human help for more than 150 years. "They're growing in an environment that may be more like environments we're going to have in the future...hotter, drier," says Charlie Brummer, director of UC Davis's Plant Breeding Center.
–MARYN MCKENNA

PHOTOS (FROM TOP): MARK STONE, UNIVERSITY OF WASHINGTON; STEVE SWANSON, NASA; LUISA DORR

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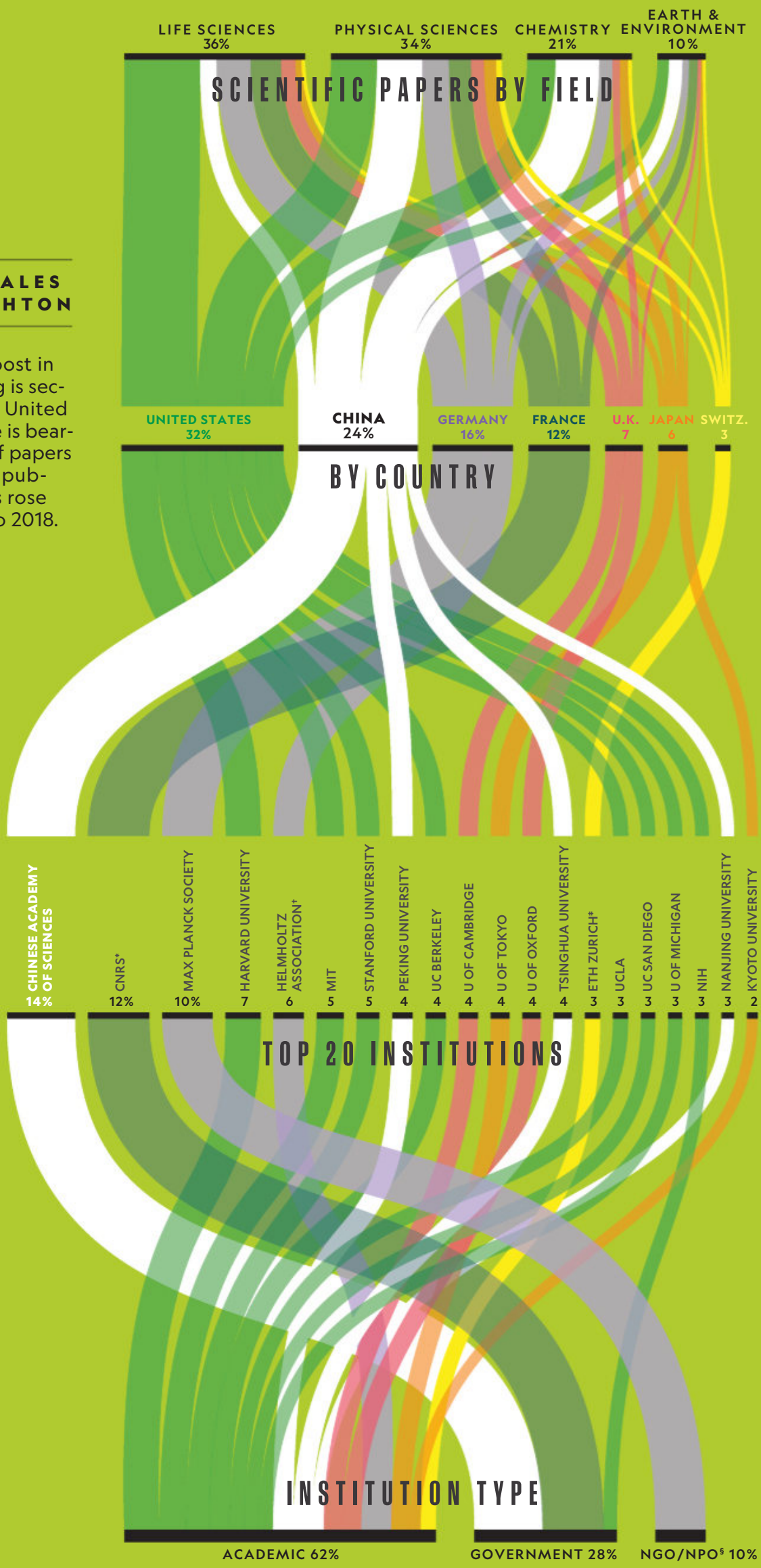
CHINA'S SCIENCE BOOM

BY **MANUEL CANALES** & **SEAN McNAUGHTON**

SCIENCE IS getting a boost in China. Research funding is second only to that of the United States, and the largesse is bearing fruit: The number of papers that Chinese scientists published in major journals rose 17 percent from 2016 to 2018.



REVERSING THE BRAIN DRAIN

In 2013 nine out of 10 Chinese students were still in the U.S. five years after earning Ph.D.'s. In 2017 more than 480,000 scholars in advanced studies abroad returned to China.

The world's largest research institution is backed by the Chinese government. The Chinese Academy of Sciences consists of 60,000 scientists in 114 institutions and maintains most of the country's big science facilities.

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NATIONAL GEOGRAPHIC | VOL. 235 NO. 5

SOARING SPIDERS

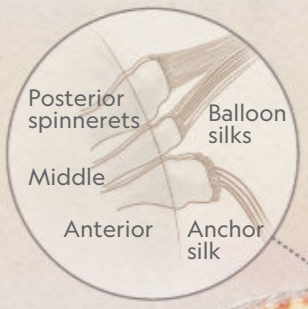
CHARLES DARWIN WAS FASCINATED by the spiders that landed on the H.M.S. *Beagle* nearly two centuries ago. Spiders don't have wings, yet they alighted on his ship 60 miles offshore. Recent research on flying spider species, however, provides some new clues as to how the Earth's electric field might help them pull off this aerial feat. They take to the skies in a process called ballooning, in which they position their bodies to catch air, spinning out silk that uses wind—and the electric field—to create lift. They may fly in search of better locations but have little control once airborne.

UPPER ATMOSPHERE (POSITIVE CHARGE)

Global circuitry
In fair weather the atmosphere holds a positive charge, while Earth's surface is negative. The charges attract one another. The electric field is strongest at high, pointy areas—such as flower tips.

Fine hairs called trichobothria can sense and react to wind and electrical conditions.

Silk glands produce multiple types of silk, released from pairs of spinnerets.



Silk may intrinsically carry a charge or acquire it from friction or from the air.

Frictional charge

Intrinsic charge

Acquired charge

Balloon silks made of 70-140 nanofibers

Spinnerets

Silk glands

Anchor silk secured by rear leg

The spider raises its front legs to sense conditions.

Ghost spider (continental species)

1

On tiptoe
The spider climbs to a high point, secures itself with an anchor silk, and tests conditions with its front legs. Then it "tiptoes" on its back legs, raises its abdomen, and releases silk.

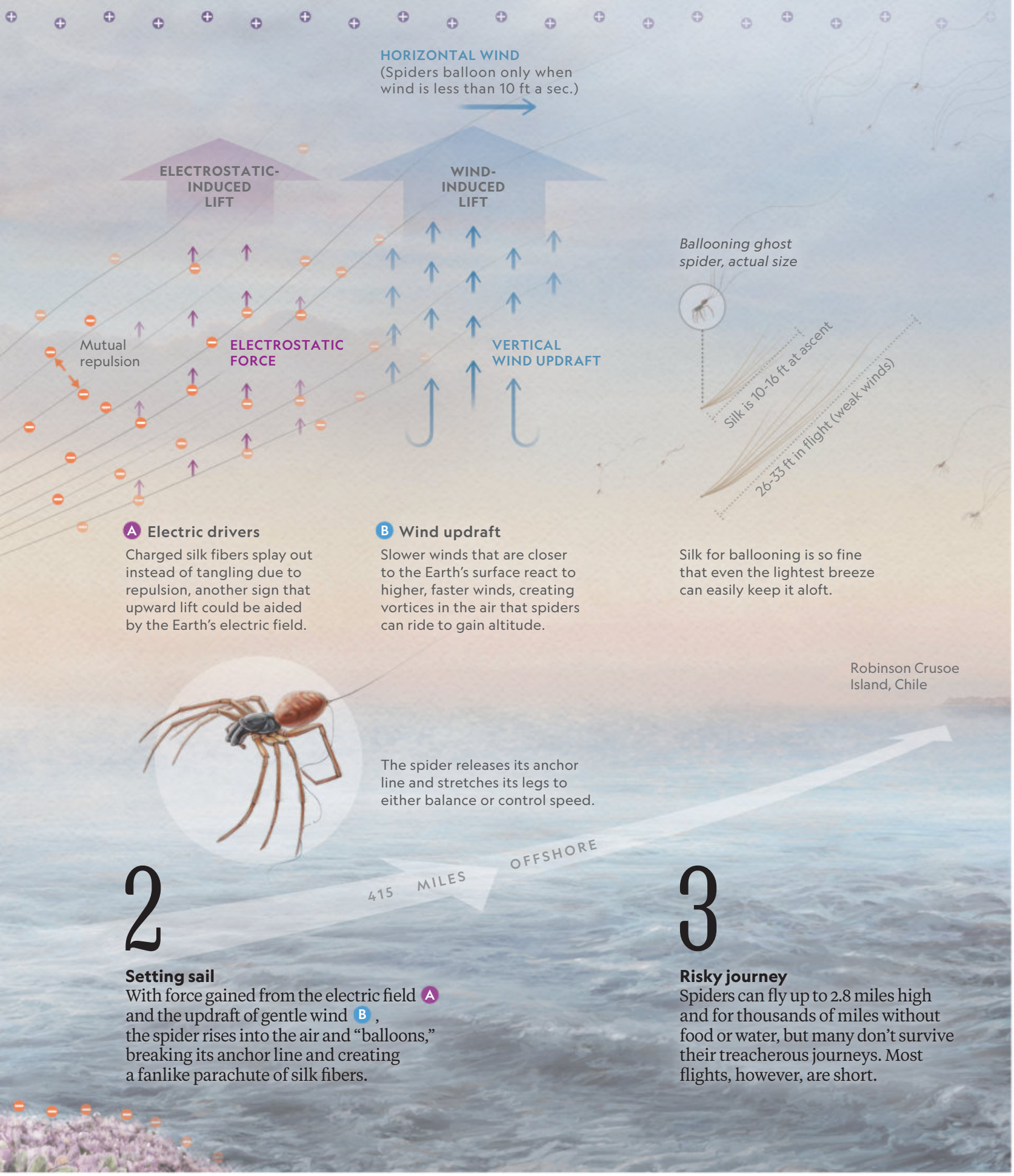
EARTH SURFACE (NEGATIVE CHARGE)

CASTAWAYS IN THE SKIES

Only a fraction of spider species fly, but those that do are great colonizers. Some may fly while carrying eggs to spread their populations, but what drives them to fly is unknown. The ghost spiders of Robinson Crusoe Island flew from mainland Chile two million years ago and have since thrived and diverged into new species.

DECODER

BY **DAISY CHUNG**



A Electric drivers
Charged silk fibers splay out instead of tangling due to repulsion, another sign that upward lift could be aided by the Earth's electric field.

B Wind updraft
Slower winds that are closer to the Earth's surface react to higher, faster winds, creating vortices in the air that spiders can ride to gain altitude.

Silk for ballooning is so fine that even the lightest breeze can easily keep it aloft.

The spider releases its anchor line and stretches its legs to either balance or control speed.

2

Setting sail
With force gained from the electric field A and the updraft of gentle wind B, the spider rises into the air and "balloons," breaking its anchor line and creating a fanlike parachute of silk fibers.

3

Risky journey
Spiders can fly up to 2.8 miles high and for thousands of miles without food or water, but many don't survive their treacherous journeys. Most flights, however, are short.

CLARE TRAINOR, NGM STAFF (MAP); MESA SCHUMACHER. SOURCES: MOONSUNG CHO, TECHNICAL UNIVERSITY OF BERLIN; ERICA L. MORLEY, UNIVERSITY OF BRISTOL; GUSTAVO HORMIGA, GEORGE WASHINGTON UNIVERSITY; ROBERT B. SUTER, VASSAR COLLEGE, *MOLECULAR PHYLOGENETICS AND EVOLUTION* 107 (2017)

A FITTING PROFESSION

1. Hoof capsule
A technical term for the hoof. The hoof capsule shown here (with shoe attached) belongs to a horse named Tonto.
2. Farrier box
This holds all the tools needed to fit and remove horseshoes, as well as to "balance," or trim, the hoof so the animal's foot is level.
3. Hoof pull-off
"Farriers are not noted for using fancy names," says Reynolds. But they use this steel tool to pull a horseshoe off a hoof.
4. Metal hoof rasp
Similar to a nail file, a hoof rasp scrapes material from the hoof and can be coarse or fine.
5. Leather chaps
Chaps protect a farrier's legs from puncture wounds and other injuries.
6. Forging hammer
Essential to a farrier's toolbox, this hammer is used for fashioning shoes.
7. Pinch vise
A vise can be helpful for holding tools in place while they're being sharpened.
8. Hoof tester
To isolate the source of an injured animal's pain so it can be treated, a farrier checks the foot for tenderness.
9. Cross peen hammer
The bladelike shape helps a farrier make the "clip," a stabilizing feature on some horseshoes.
10. Anvil
Farriers and blacksmiths shape metal on anvils. Reynolds brings his, which weighs 101 pounds, on all his rounds.

PHOTOGRAPH BY **MARK THIESSEN**

WHEN IT COMES TO HORSESHOES, one size—or shape—hardly fits all. There are thousands of styles worldwide, and Arvin Reynolds is familiar with many of them. Reynolds is a farrier, or "horseshoe-er," as he sometimes puts it. Based in Washington, D.C., he cares for hundreds of equine feet, including those belonging to the horses of the United States Park Police. Checkups are typically every six weeks, says Reynolds, and not because the animals get sick frequently or need new shoes. Rather, hooves, like human toenails, grow continually and require regular trimming. **–CATHERINE ZUCKERMAN**

U.S. PARK POLICE, HORSE MOUNTED UNIT TRAINING BARN, WASHINGTON, D.C.

"The more we understand epilepsy

the closer we get to wiping it out."

Loretta / Epilepsy Patient

Henrik / Epilepsy Researcher

How far have we come with epilepsy research? Scientists are uncovering more about the nervous system at the molecular and genetic levels, driving innovative treatments for several neurological disorders. And with every new treatment we discover, we're that much closer to the cure. **This is the future of medicine. For all of us.**

Innovation.org

GOBOLDLY®

America's Biopharmaceutical Companies®

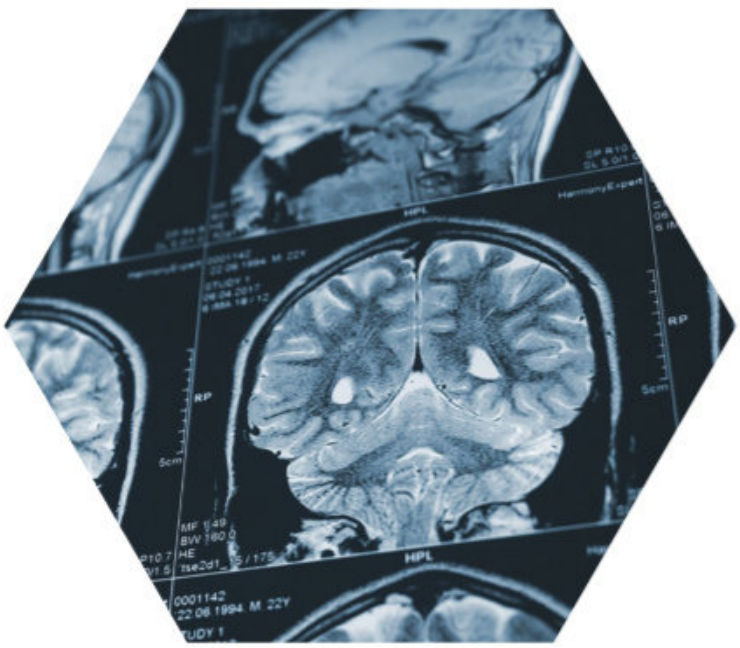
PERSONALIZING EPILEPSY TREATMENT

Biopharmaceutical researchers are working to create a future where patients get the right medicines the first time.

Epilepsy is one of the most common serious neurological conditions in the United States, affecting some 3.4 million people. Treating epilepsy, however, requires an innovative approach since the types, severity, and frequency of epilepsy's characteristic seizures vary from person to person. In some studies, fewer than half of newly diagnosed epilepsy patients responded well to the first medicine they were prescribed, and many patients spend years cycling through therapeutic options before arriving at what works. In still other patients, multiple treatments fail because the epilepsy is drug resistant.

Georgia-based biopharmaceutical researcher Edward Han-Burgess and his team are working to take the mystery out of managing epilepsy by developing targeted treatments. Known as personalized, or sometimes precision, medicine, this emerging scientific field looks at how a person's genetic code and health history affect disease pathology, and uses mathematical computer modeling to identify patterns in massive amounts of epilepsy data. Combining the two techniques promises to allow researchers to one day predict the most appropriate treatment for each individual epilepsy patient—the first time.

The science is leading edge, but to Han-Burgess and his fellow biopharmaceutical researchers, the mission is personal. Prominently featured in the team's lab is a poster of a local woman with epilepsy whose own struggle to control her seizures serves as a constant source of inspiration. "She had her first seizure in a grocery store with her daughter," Han-Burgess explains. "It took her two and a half years to find an epileptologist, and then another two and a half years to find the right treatment that worked for her."

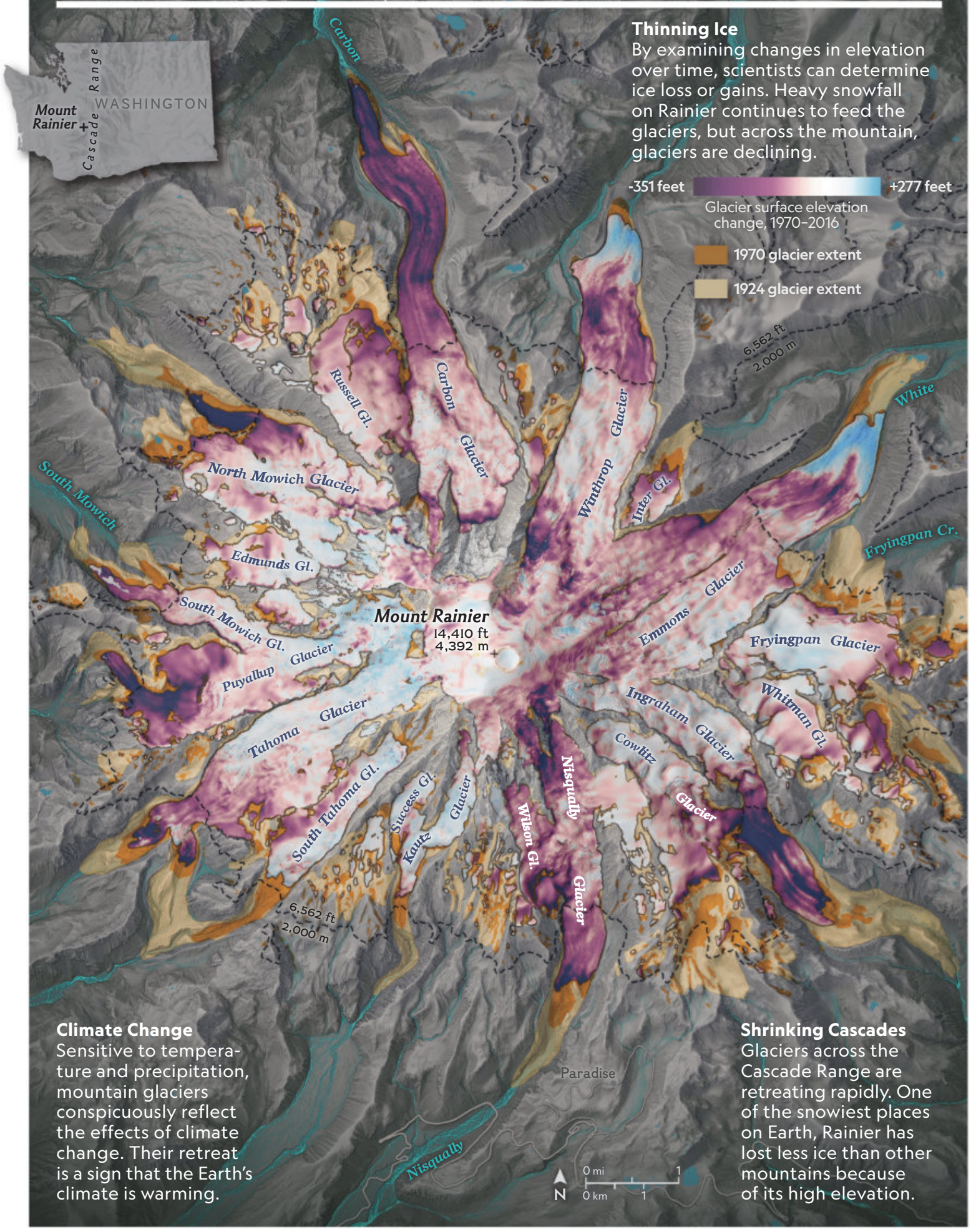


"She had her first seizure in a grocery store with her daughter," Han-Burgess explains. "It took her two and a half years to find an epileptologist, and then another two and a half years to find the right treatment that worked for her."

MOUNT RAINIER IS SHEDDING ITS GLACIERS

WASHINGTON'S MOUNT RAINIER boasts the largest collection of glaciers on a single peak in the contiguous United States. But those glaciers have lost approximately 18 percent of their volume since 1970. The most substantial thinning is occurring on south-facing glaciers and at elevations below 6,562 feet (2,000 meters). During extreme weather this could set the stage for massive floods and debris flows in the park and surrounding areas.

BY **IRENE BERMAN-VAPORIS** AND **ERIC KNIGHT**



Thinning Ice
By examining changes in elevation over time, scientists can determine ice loss or gains. Heavy snowfall on Rainier continues to feed the glaciers, but across the mountain, glaciers are declining.

-351 feet +277 feet
Glacier surface elevation change, 1970–2016
1970 glacier extent
1924 glacier extent

Climate Change
Sensitive to temperature and precipitation, mountain glaciers conspicuously reflect the effects of climate change. Their retreat is a sign that the Earth's climate is warming.

Shrinking Cascades
Glaciers across the Cascade Range are retreating rapidly. One of the snowiest places on Earth, Rainier has lost less ice than other mountains because of its high elevation.

SOURCES: DAVID SHEAN, UNIVERSITY OF WASHINGTON; SCOTT BEASON, PAUL KENNARD, AND JON RIEDEL, NATIONAL PARK SERVICE; USGS

Some things are *bigger* than banking

(Like a tent for two.)

If adventure travel is your thing, it's our thing too. While your breakfast might not be raccoon proof, our mobile banking app is. And knowing your money is secure is always a breath of fresh air.

regions.com/BiggerThanBanking

REGIONS

TOADS' SEX LIFE HINGES ON FINDING THE PERFECT POOL

THE MALE YOSEMITE TOAD *(Anaxyrus canorus)* can mate like mad every year—for about two weeks. Only in late spring. And only in wet meadows, at elevations above 4,800 feet, in California's Sierra Nevada. The male will wait in a pool, trilling. A female drawn by his mating call (*canorus* means "melodious") will enter the water and submit to his advances—*if* the pool suits. Toads have precise specifications for where they'll breed and leave their eggs, says U.S. Forest Service ecologist Christina Liang.

For six years Liang and colleagues observed 143 pools across 19 meadows in the toads' range. Toads seek pools that will support life from the

springtime when eggs are laid through late summer when toadlets emerge. By tracking which pools were and were not occupied, researchers found differences in conditions were at times quite small. Toads chose wider pools with more surface area; pools with warmer water (a mean temperature of 76.7°F versus 71.2°F); and pools that were deeper—by only about the diameter of a standard pencil.

To mate, Liang says, the male "clamps onto" the female's back—but "she has the final say" on where to release eggs and may move around with him attached until she chooses a spot. Once she releases her eggs and he fertilizes them, she'll leave; he'll resume calling.

The Yosemite toad is considered endangered, and its numbers are falling. Scientists say the amphibian chytrid fungus is one reason, but climate change also may contribute to some pools drying up before tadpoles mature. The species "is on that knife's edge," Liang says, "where these really small changes in environmental conditions can have potentially large effects." —PATRICIA EDMONDS

THIS TOAD WAS PHOTOGRAPHED AT UC BERKELEY'S MUSEUM OF VERTEBRATE ZOOLOGY. PHOTO: JOEL SARTORE

Finding Dignity in a Dirty Job

BY **ANDREA BRUCE**

THIS IS EXILIEN CENAT. He is a *bayakou,* the Haitian term for laborers who empty latrines. I took his photo while he was cleaning out a pit toilet that served several families in Port-au-Prince. Despite the unpleasantness of his job, Exilien represents a solution—a crude one—to the deadly problem of poor sanitation.

I'd been assigned to photograph a *National Geographic* story on open defecation, a subject that didn't disturb me too much. I've covered wars and conflicts in places where sanitation is not a priority. The difficulty, I thought, would lie in making visually interesting images out of such a banal subject—something so universal that everybody does it.

But following people to the bathroom, or wherever they go, is surprisingly tough. People can't even talk about this most basic of human actions, let alone discuss it in a way that brings positive change to their communities. Yet without proper sanitation, you can't have clean water.

Haiti's bayakou perfectly distill many of our issues about defecation. People throw stones at them, almost as if embarrassed that they need someone like the bayakou to clean up their waste. Therefore, many bayakou operate at night and hide what they do—even from their families. Even so, the bayakou are well paid and in high demand. Port-au-Prince's precarious sewage system rests on their shoulders.

Finding a bayakou who would agree to be photographed proved to be the most difficult part of this project. But after five months of trying, I connected with Exilien. He was eager for me to document his work because he rejects the idea that his profession is shameful. He is proud of what he does and wants to be respected.

THE BAYAKOU OF PORT-AU-PRINCE, HAITI, PERFORM A SERVICE THAT IS ESSENTIAL TO THE HEALTH OF THE CITY. AND YET THEY MUST KEEP THEIR WORK A SECRET.

EXILIEN SAID HE GETS SICK OFTEN. BY THE END OF THE NIGHT, HIS EYES WERE NEARLY SWOLLEN SHUT.

I arranged to meet Exilien and his two colleagues late at night in a courtyard between several houses. My photo editor had been concerned about the conditions so I'd packed protective gear: face masks and scarves (to block the smell) as well as rain gear (to protect my clothes). But when it came time to put it all on, I found I couldn't do it. I didn't want to make him feel like his job was disgusting. It's his profession, something only a few people know how to do, and he does it well.

Most of the lights in the courtyard were out, and the families were asleep. The toilet in the outhouse hadn't been emptied in more than a year. Exilien began his work by reaching into the hole to scoop out the freshest layer. The stench permeated the air. His two colleagues deftly dumped the sewage into what looked like old seed sacks, tying them up perfectly without any leaks. They had more experience than Exilien and had graduated from cleaning the hole.

In order to endure the smell and discomfort, the three men drank and smoked throughout the night. One guy would hold a cigarette so Exilien could take a few puffs without touching the cigarette with his soiled hands.

Once the contents of the hole were beyond his reach, Exilien climbed down into it. He told me that he'd come across snakes and human remains in toilets. Snakes were his enemies, he said. Other bayakou told me about encountering live wires and suffering electric shocks.

Those are the dangers they can see. Hidden from sight are the diseases. Cholera still kills in Haiti, although treatment centers make it less deadly in the city. Exilien said he gets sick often. By the end of the night, his eyes were nearly swollen shut.

Bayakou wash themselves very carefully after a night's work (as did I—and I threw away what I was wearing). Most work naked to avoid ruining clothes. Exilien kept his on for most of that night, I think because I was there. But in the end, after he'd cleaned himself and changed, he had to strip down completely.

The owner of the toilet expressed dissatisfaction with how it had been cleaned. So Exilien, after removing his fresh clothes, went back to do more.

Afterward, the three men loaded the sacks of sewage into a cart and rolled them down to the river, where they dumped the bags in the water. There's a government facility that treats sewage, but you need a truck to get there, and they don't have one.

Exilien wanted people to see what he does. No one wants to be invisible. That's what I find so powerful about photography. When you take someone's picture, you are telling them: Your life is important. □

Andrea Bruce focuses on people living in the aftermath of war. Her story on sanitation ran in the August 2017 issue.

Exilien Cenat removes human waste from a multifamily pit toilet by hand. The job pays well but it is not respected.

LEGAL NOTICE

If you subscribed to Premium Cable and paid a rental fee for a Set-Top Box, you could receive benefits from a Class Action Settlement.

Si desea recibir esta notificación en español, llámenos o visite nuestra página web.

A settlement has been reached with Defendants Comcast Corporation, Comcast Holdings Corporation, Comcast Cable Communications, LLC, and Comcast Cable Communications Holdings, Inc. (collectively "Comcast") about alleged antitrust violations and unfair trade practices related to the rental of "Set-Top Boxes" to Comcast's Premium Cable subscribers. The Settlement provides benefits to former and current Comcast customers who file a valid Claim Form.

The United States District Court for the Eastern District of Pennsylvania will hold a hearing to decide whether to give final approval to the Settlement, so that the benefits can be issued. Those included subscribers have legal rights and options, such as submitting a claim for benefits or excluding themselves from or objecting to the Settlement. More information is in the Detailed Notice, which is available at www.SetTopBoxSettlement.com.

WHAT IS THIS ABOUT?

The lawsuit claims that Comcast engaged in various anti-competitive activities and unfair trade practices related to the rental of Set-Top Boxes to Comcast's Premium Cable subscribers. The claims asserted in the lawsuit can be found in the Fourth Amended Consolidated Class Action Complaint, available at www.SetTopBoxSettlement.com. Comcast denies all of the claims and allegations in the lawsuit and says it did nothing wrong.

WHO IS INCLUDED?

The Court decided that the Class includes all persons who: (a) resided within the states of California, Washington, or West Virginia during the Class Period or have opted out of Comcast's arbitration clause as recorded within the arbitration clause opt-out list kept at Comcast's offices; and (b) paid Comcast a rental fee for a Set-Top Box at any time during the Class Period.

The Class Period is from January 1, 2005 to September 5, 2018.

If you are unsure whether you opted out of Comcast's arbitration clause, then you may call 1-888-748-8055 or email info@settopboxsettlement.com to determine whether you are recorded as an arbitration clause opt-out within the arbitration clause opt-out list kept at Comcast's offices.

WHAT DOES THE SETTLEMENT PROVIDE?

Subscribers who are Settlement Class Members and submit a valid Claim Form can receive between $10.00 and $15.00 payable by check. In lieu of that cash payment, Current Subscribers who are Settlement Class Members and submit a Claim Form have the option of receiving credits redeemable for a variety of Comcast services. Benefit options may vary depending on the period of time you rented a Set-Top Box and how many Set-Top Boxes you rented. If more than $15.5 million worth of claims are submitted by eligible claimants, the benefits will be distributed on a pro rata basis. If less than $15.5 million worth of claims are submitted by eligible claimants, Comcast is entitled to retain the balance. Details on all of the Settlement benefits are included in the Detailed Notice and the Settlement Agreement, which are available at www.SetTopBoxSettlement.com.

HOW DO YOU ASK FOR BENEFITS?

To get a payment you must submit a Claim Form. You can quickly and easily submit your claim online at www.SetTopBoxSettlement.com. You can also request a paper Claim Form be sent to you by calling 1-888-748-8055. The claim deadline is **August 31, 2019**.

YOUR OTHER OPTIONS.

If you do not want to be legally bound by the Settlement, you must exclude yourself by **July 9, 2019**. If you stay in the Settlement, you may object to it by **July 9, 2019**. The Detailed Notice explains how to exclude yourself or object. The Court will hold a hearing in the case on **September 10, 2019**, to consider whether to approve the Settlement, and a request by Settlement Class Counsel for attorneys' fees, costs, and expenses of up to $1.1 million and incentive awards, which will not exceed $1,000, to the four named Plaintiffs for their services on behalf of the Settlement Class. Members of the Settlement Class will not be responsible for the fees and expenses of Class Counsel, and the payment of attorneys' fees and expenses will not reduce the benefits to the Settlement Class. You or your own lawyer, if you have one, may ask to appear and speak at the hearing at your own cost, but you do not have to. For more information, call or go to the website shown below.

www.SetTopBoxSettlement.com
1-888-748-8055

THE CHALLENGE IS CLEAR

More than nine million tons of plastic waste end up in our ocean each year and without interventions, this number is expected to almost double by 2025.

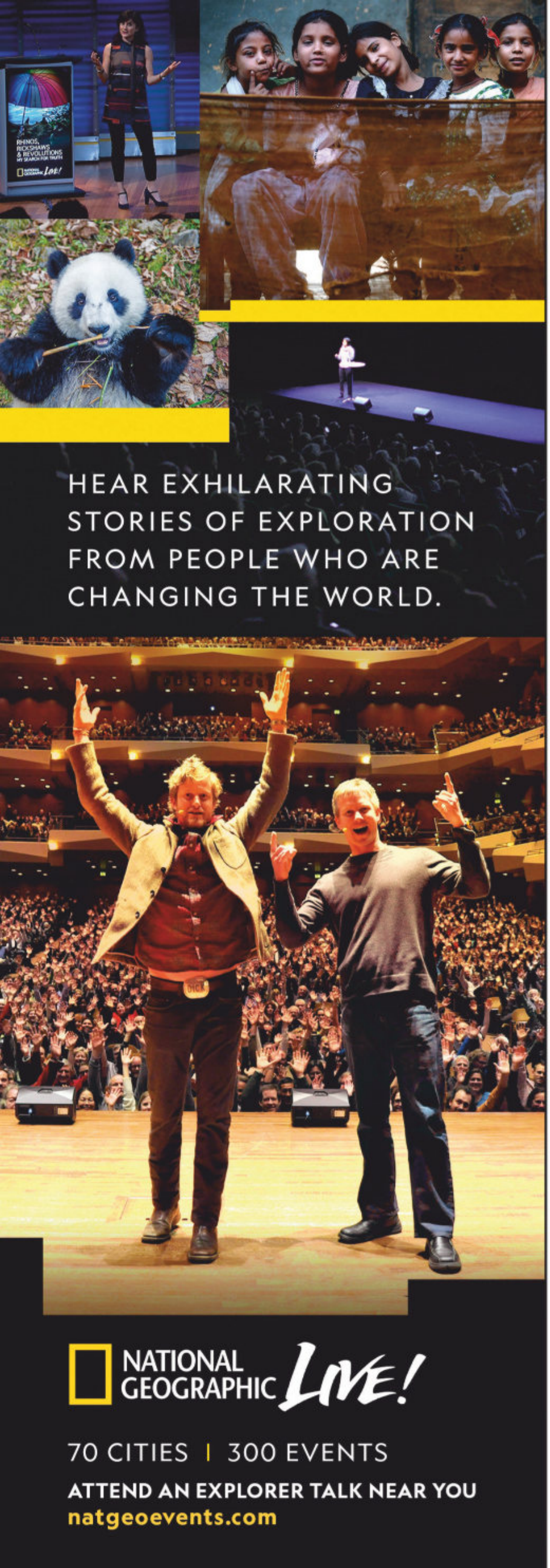
The Ocean Plastic Innovation Challenge asks problem solvers around the globe to develop novel solutions to tackle the world's plastic waste crisis.

PHOTO: JUSTIN HOFMAN

Submit your solution by June 11, 2019 at

oceanplastic-challenge.org

NATIONAL GEOGRAPHIC | sky ocean ventures



IF YOU RECEIVED A CASH DISTRIBUTION IN CONNECTION WITH CERTAIN AMERICAN DEPOSITARY RECEIPTS ("ADRS") FOR WHICH CITIBANK N.A. SERVED AS DEPOSITARY OR IF YOU CURRENTLY OWN SUCH ADRS, YOUR RIGHTS MAY BE AFFECTED.

Pursuant to Federal Rule of Civil Procedure 23 and Court Order, *Merryman et al. v. Citigroup, Inc. et al.*, No. 1:15-cv-09185-CM-KNF (S.D.N.Y.) has been provisionally certified as a class action for settlement purposes and a settlement for $14,750,000 in cash and certain additional non-monetary relief has been proposed, which, if approved, will resolve all claims in the litigation. This notice provides basic information. It is important that you review the detailed notice ("Notice") found at the website below.

What is this lawsuit about: Plaintiffs allege that, during the relevant time period, Citibank N.A. (the "Depositary") systematically deducted impermissible fees for conducting foreign exchange from dividends and/or cash distributions issued by foreign companies, and owed to ADR holders. The Depositary has denied, and continues to deny, any wrongdoing or liability whatsoever.

Who is a Class Member: Persons or entities (1) who received cash distributions from the ADRs listed in Appendix 1 to the Notice from January 1, 2006 to September 4, 2018, inclusive, and were damaged thereby (the "Damages Class"); and/or (2) who currently own the ADRs listed in Appendix 1 to the Notice (the "Current Holder Class" and, together with the Damages Class, the "Class").

What are the benefits: If the Court approves the settlement, the proceeds, after deduction of Court-approved notice and administration costs, attorneys' fees and expenses, will be distributed pursuant to the Plan of Allocation in the Notice, or other plan approved by the Court.

If you are a Current Holder Class Member, the Settlement also provides additional non-monetary relief related to the conversion of foreign currency of cash distributions paid by eligible ADR issuers pursuant to a deposit agreement.

What are my rights: If you are a Damages Class Member and you hold (or held) your ADRs directly and are listed on the Depositary's transfer agent records, you are a Registered Holder Damages Class Member and *do not* have to take any action to be eligible for a settlement payment. However, if you hold (or held) your ADRs through a bank, broker or nominee and are not listed on the Depositary's transfer agent records, you are a Non-Registered Holder Damages Class Member and you *must submit* a Claim Form, ***postmarked by August 12, 2019***, to be eligible for a settlement payment. Non-Registered Holder Damages Class Members who do nothing will not receive a payment, and will be bound by all Court decisions.

If you are a Class Member and do not want to remain in the Class, you may exclude yourself by request, ***received by June 7, 2019***, in accordance with the Notice. If you exclude yourself, you will *not* be bound by any Court decisions in this litigation and you will *not receive a payment*, but you will retain any right you may have to pursue your own litigation at your own expense concerning the settled claims. Objections to the settlement, Plan of Allocation, or request for attorneys' fees and expenses must be ***received by June 7, 2019***, in accordance with the Notice.

A hearing will be held on **July 12, 2019 at 10:00 a.m.**, before the Honorable Colleen McMahon, at the Daniel Patrick Moynihan United States Courthouse, 500 Pearl Street, New York, NY 10007, to determine if the settlement, Plan of Allocation, and/or request for fees and expenses should be approved. Supporting papers will be posted on the website once filed.

For more information visit www.CitibankADRSettlement.com, email info@CitibankADRSettlement.com or call 1.866.680.6138.

FEATURES

A female crocodile guards her nest of eggs beside the Mussicadzi River in Mozambique's Gorongosa National Park.

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'IN THE REALM OF CONSERVATION, WHERE TOO MANY INDICATORS HERALD GLOOM AND DESPAIR, SUCCESS ON SUCH A LARGE SCALE IS RARE.'

PHOTO: CHARLIE HAMILTON JAMES

LITTLE PIECES, BIG PROBLEMS

Photographs by David Liittschwager

Newborn fish are eating

tiny bits of plastic trash

instead of food.

If the baby fish die,

there will be fewer big fish

—and that could rattle the food chain.

By Laura Parker

Fish nurseries off Hawaii are now a microplastic mess.

The naturally oily surface slicks in which many ocean fish come of age are rich in plankton and other fish food—and now also in plastics, according to researchers at the National Oceanic and Atmospheric Administration in Honolulu. They've been towing fine-mesh nets through slicks off the Big Island and analyzing each haul. Here, a scribbled filefish, about 50 days old and two inches long, navigates a soup of plastic.

PREVIOUS PHOTO

The blue glove hasn't been in the water long enough to suffer the fate of most ocean plastic, which is to be shredded into small bits, or microplastics, by waves and sunlight. The larval fish below the thumb is a driftfish; the striped one at the base of the index finger is a mahi-mahi.

ALL PHOTOGRAPHS MADE AT A TEMPORARY FIELD LAB, NOAA PACIFIC ISLANDS FISHERIES SCIENCE CENTER, KAILUA KONA, HAWAII, EXCEPT WHERE NOTED.

On the left, fish food. On the right, plastic.

A dollop of surface water from the English Channel contains a shrimplike krill, about a third of an inch long; a smaller decapod crustacean; and an orange sea star just emerging from its filmy floating larval stage. The white chip and the fraying red fiber on the right are polyethylene—but to a young fish they too may look like food. Three percent of the larval fish caught for a 2017 study by researchers at Plymouth Marine Laboratory and the University of Plymouth had eaten microplastic fibers.

PHOTOGRAPHED AT MARINE BIOLOGICAL ASSOCIATION, PLYMOUTH, U.K.; PLASTIC IDENTIFICATION PROVIDED BY UNIVERSITY OF PLYMOUTH

PLANET OR PLASTIC?

Not long ago I went snorkeling in the Pacific Ocean, a half mile off the southwest coast of Oahu. The flanks of the Hawaiian island are steep there, and the bottom quickly disappeared beneath us as we motored out to the site. Looking back, I could see the green slopes of the Waianae Range rising to 4,000 feet behind the beach. Normally the mountains shield the water here from the trade winds. But on that day a breeze created a light chop that nearly obscured what I had come to see: a thin, oily slick of surface water, rich in organic particles, in which newborn fish were feeding and struggling to survive their first precarious weeks.

Plunging my face into the sheen, I found myself looking inside a fish nursery: The water was dotted with life you would ordinarily never notice. Fish eggs drifted like tiny lanterns, their yolk sacs glowing in the sunlight. Fish larvae small as ladybugs darted about. A sergeant major damselfish the size of a dime appeared huge by comparison as it fluttered past. Below us, a school of 12-inch, bigeye scad—like mackerel but with enormous eyes—fed on everything that had the misfortune of being small.

My guides that day, oceanographer Jamison Gove and fish biologist Jonathan Whitney of the National Oceanic and Atmospheric Administration in Honolulu, are nearly three years into a research project that aims to make sense of this chaotic scene. The larval stage is the "black box" of fisheries science: Fertilized eggs go in, and young fish come out—but what happens inside remains sketchy. The larval fish are so small and fragile they're exceedingly difficult to study. The overwhelming majority will never become adults. Yet fish populations around the world, and the animals that eat them, depend on just how many larval fish make it, and in what condition.

What Gove and Whitney have found lately—and what David Liittschwager's photographs of their water samples document—is that fish and wholesome fish food are not the only things collecting in the slicks off Hawaii. Microplastics, tiny shreds of human trash, are there as well, and in such abundance that larval fish are eating them in their first days of life.

For newborn fish, to eat is to live another day; if their first meal is plastic, they're not consuming the calories they need to sustain them until the second. "They've beaten a lot of odds to get this far," Gove says. "They hatched, they found the slick, they're feeding and growing. This is one-tenth of one percent that made it this far; they're the lucky ones. And now plastics are coming in."

"The most critical moment is that first feeding," Whitney says. "If they get a piece of plastic, that could be it. A single thread in the stomach of a larval fish is potentially a killer."

Plastic waste, mostly from rivers or careless dumping on land, washes into the oceans at an average rate of about nine million tons a year, according to a 2015 study by Jenna Jambeck of the University of Georgia. The visible trash, along with heartbreaking images of its impact on everything from turtles to birds to whales, has generated a public outcry. But sunlight, wind, and waves eventually break down ocean plastic to bits that are barely visible. One of the biggest unknowns—and concerns—is the effect that these microplastics, smaller than a fifth of an inch, might be having on fish.

Fish provide critical protein to nearly three billion people and countless seabirds and other marine animals. But fish stocks worldwide have fallen by half since 1970, surveys show. Populations of the largest predatory fish, such as tuna, have fallen even more. The decline is largely because of overfishing, but pollution and waters warmed and acidified by climate change are having a growing impact.

As long ago as the early 1970s, scientists were finding plastic pellets—the material used to manufacture plastic goods—in the stomachs of fish caught off New England and Great Britain. More recent studies have documented the presence of even smaller microplastic particles in a growing array of adult fish. Larval fish have been studied much less but are likely to be more vulnerable to microplastics, as they

A grid painted on a petri dish helps a NOAA technician sort through a sample and identify tiny organisms, such as the larval sergeant major damselfish on the left, just outside the middle row. The squares are one centimeter (.39 inch) across.

The nonprofit National Geographic Society, working to conserve Earth's resources, helped fund this article.

Off Hawaii, a single eight-minute tow of the NOAA team's net yields a plethora of living organisms (left) and plastic (right).

Pushed into a surface slick by converging currents, they're separated in the lab by a technician with tweezers. A computer program counts the plastic pieces and measures each one; the technician uses a microscope to identify the creatures.

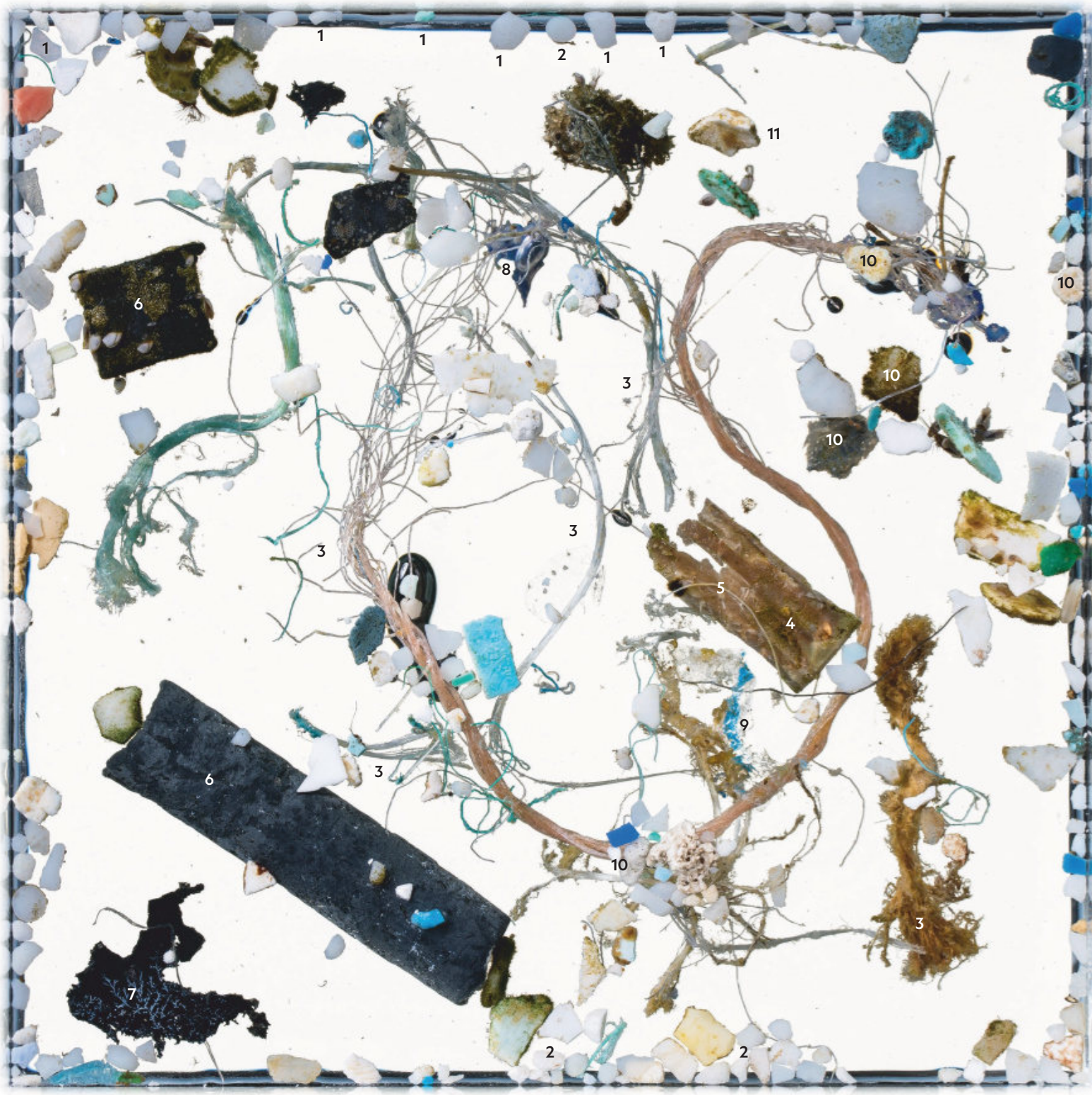
LIVING ORGANISMS

Most of the organisms the NOAA researchers collect are larvae.

1. Hound needlefish
2. Sergeant major damselfish
3. Amberjack
4. Chub
5. Triggerfish
6. Sailfin flying fish
7. Flying fish
8. Man-of-war fish
9. Bigwing halfbeak
10. Mahi-mahi
11. Tropical halfbeak
12. Flat needlefish
13. Large-scaled lanternfish
14. Decapod shrimp larvae
15. Purple pelagic snail
16. Blue shrimp
17. Crab larvae, megalops stage
18. Pelagic snail
19. Blue copepod
20. Medusa (jellyfish)
21. Polychaete worm
22. Blue button hydroid
23. Pelagic sea slug
24. Flatworm
25. Comb jelly
26. Peanut worm

SHOWN AT ACTUAL SIZE

If a newborn fish eats microplastic, it's not consuming the calories it needs to survive. It may not get another shot: The odds against young fish are long enough already.



PLASTIC TRASH

Most of the plastic waste collected in the researchers' nets is in tiny, degraded fragments that can be harder to identify than the living organisms.

1. Polypropylene or polyethylene fragment
2. Preproduction pellet, polypropylene or polyethylene
3. Braided line from fishing or cargo net
4. Marker-pen cap
5. Monofilament fishing line, nylon
6. Tube for spacing oysters on oyster farm
7. Flexible low-density polyethylene
8. Possible latex balloon
9. Packaging sheet, probably polyethylene food wrapper
10. Expanded polystyrene, probably from a take-out container
11. Soda bottle cap, high-density polyethylene

are to everything else. "Any stressor will likely have more of an impact on early life stages than later life stages," says Susanne Brander, a toxicologist at Oregon State University who is studying how plastics might affect the growth of fish.

Most ocean fish are terrible parents. A few species guard their eggs on the seafloor; others protect them inside their mouths. But most fish release thousands or even millions of eggs and sperm into the wide ocean and never see their offspring. When eggs hatch a day or two later, they're on their own.

Newly hatched fish look misshapen, heads oversize, tails barely formed. They have to eat like crazy to grow into their body. Whereas human babies develop in the shelter of the uterus, fish mainly develop after they emerge into an unforgiving world.

"They hatch super early," Whitney says. "They have small brains; some fins aren't even formed. Their liver isn't fully developed. Or their hearing or seeing. They are only partially developed, but they are actively swimming, eating, fending for themselves."

Predators or starvation will get most of them. "That's why fish spawn so many eggs," says Su Sponaugle, an Oregon State University marine ecologist who specializes in the early life stages of fish. "They have to hedge their bets."

The larval phase is treacherous every step of the way—starting with the need for the larvae to find food, which they do in a surface slick. Surface slicks form mostly in coastal regions around the world, wherever currents, tides, or subsurface waves cause water to converge and concentrate the organic gunk that floats in it. Slicks can be seen by satellite as long, squiggly ribbons that run parallel to coasts.

Some larval fish swim to slicks, some drift, as do eggs not yet hatched. Predators converge on slicks too. If a baby fish manages to avoid being eaten and to find enough food, it will be about two inches long when it heads back to its permanent habitat—a reef, say. The right current will transport it there, the wrong one out to sea.

Most ocean fish are terrible parents: They never see their offspring.

"If you miss an island, good luck with that. If there's no reef, you cannot complete your life cycle," Sponaugle says. Life for larval fish was a crapshoot even before they met our plastic trash.

Whitney and Gove came to ocean science and Hawaii by happenstance. Whitney, 37, grew up in New Jersey with a kid's plan to become a veterinarian. He arrived in Honolulu in 2006 as a volunteer for a census of humpback whales. In graduate school he worked his way down to the tiniest organisms of the sea.

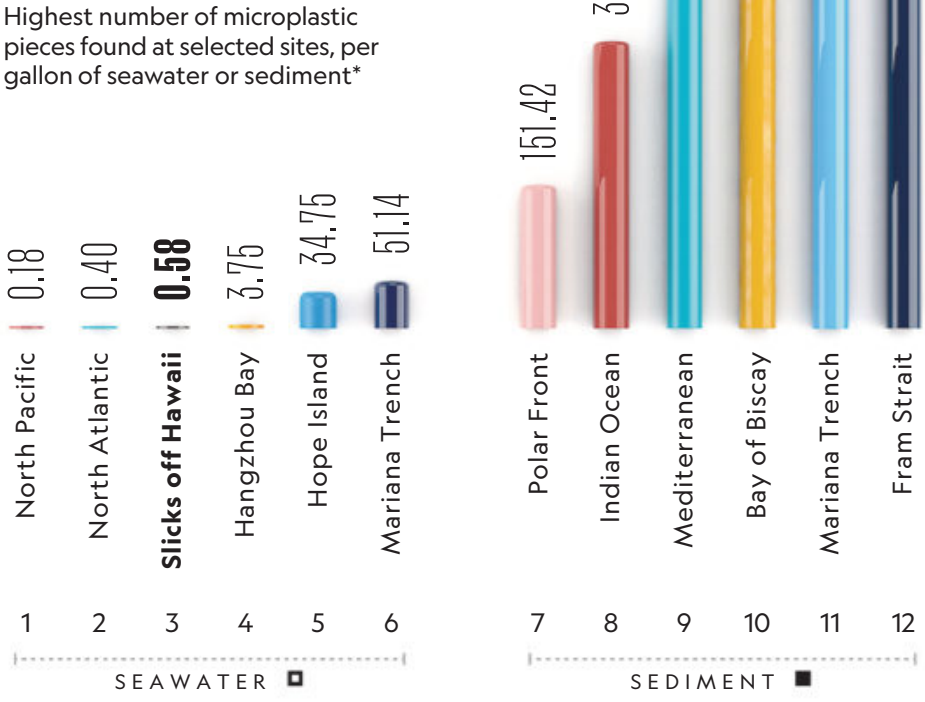
Gove, 40, grew up in San Diego and learned to surf before he could read. A summer job with NOAA convinced him the ocean was more than a playground. After helping to cut 70 tons of abandoned fishing gear from Hawaiian coral reefs, Gove enrolled in graduate school to become an oceanographer. He specialized in how winds, tides, and waves affect ocean ecosystems and surface slicks in particular.

Slicks are transient—they break up in rough weather—which makes studying them a challenge. Gove and Whitney took me to see a slick off Oahu because it was close to their lab, but their main research site is on the west side of Hawaii, the Big Island, where two large volcanoes provide an even better wind shadow than Oahu's Waianae Range. The steep drop-off of the seafloor has proved to be a surprise bonus: The slicks attract an oceanic convention of not only reef fish but also fish from greater depths, including commercially important mahi-mahi, swordfish, and marlin.

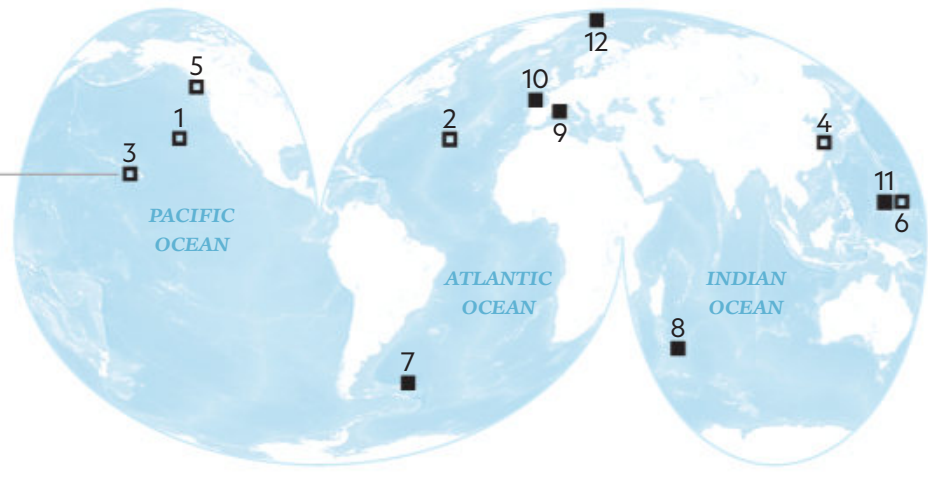
Plastic profusion

From its surface slicks that foster baby fish to its most remote depths, the ocean is full of plastic. It's prevalent off coastal cities, say researchers, but currents also gather it in the middle of the oceans. Much of it breaks down into microplastics, which, over time, accumulate on the seafloor. But it's the plastic in surface waters that likely causes the most harm to wildlife.

Highest number of microplastic pieces found at selected sites, per gallon of seawater or sediment*



Off Hawaii, currents that sweep fish eggs and larvae into slicks also collect plastic, dramatically increasing its concentration.



3,028
2,650
8,328
13,109

*COLLECTION METHODS VARY. ALBERTO LUCAS LÓPEZ, RYAN T. WILLIAMS, AND CLARE TRAINOR, NGM STAFF. FOR SOURCE DETAILS, GO TO *NGM.COM/MAY2019*.

"One of the coolest things we found was the diversity," Whitney says. "We've got deep-sea fish, mid-ocean fish, and reef fish, all interacting at the surface for the first few weeks of their lives. It was incredibly unique. I can't think of any other place on Earth where babies from different areas share nursery grounds."

He and Gove expected to find plastics in their slicks; the Hawaiian chain is in the drift pattern of the Great Pacific Garbage Patch. But they never intended to join the growing hunt for microplastics that has overtaken the work of so many marine scientists. Their focus was basic research on larval fish. Their samples contained such loads of plastic, however, that they had to revise their project.

The preliminary results indicate that slicks concentrate plastics even more than they do larval fish. In the water outside slicks, Whitney and Gove found nearly three times more larval fish than microplastics. Inside slicks, the situation was reversed: Microplastics outnumbered larval fish by more than seven to one. On average there was almost 130 times as much plastic inside slicks as outside.

"We didn't have any idea we would find such concentrations," Gove says. One of the first fish they dissected had plastic in its gut.

What harm such plastic is causing is still unsettled science. But in lab tests, some clues have emerged. Plastic reduces the appetites and growth rates of fish that consume it. That could affect reproduction and ultimately population size. "The larger a female fish is, the more eggs she can carry and the higher number of offspring she can produce," Brander says.

In their lab, Whitney and Gove oversaw the dissection of more than 650 larval fish, most of them between one-third of an inch to half an inch in length. They found plastic in 8.6 percent of the ones caught in slicks. That doesn't sound like much, and outside slicks the percentage was less than half that—but scientists know that small changes in the survival of larval fish can translate into large changes in fish populations, with cascading effects up the food chain.

They didn't expect so much plastic. One of the first baby fish they dissected had plastic in its gut.

The NOAA researchers found tiny blue strands of polyethylene and polypropylene, commonly used to make fishing gear, in the stomachs of larval swordfish, marlins, and five other species. The strands look a lot like the food that larval fish crave: tiny copepods, bluish crustaceans with long, skinny antennae.

In larval mahi-mahis, Whitney and Gove found no plastic. They're not sure why. Was it because eyesight develops earlier in mahi-mahis, making them better than other species at distinguishing plastic from prey? Or was it because the mahi-mahis that ate plastic had died and escaped detection?

Flying fish appear to eat plastic especially frequently. Besides serving as prey for larger fish, including sharks, flying fish are primary prey for 95 percent of Hawaiian seabirds. Are birds ingesting plastic with their flying fish, and is that affecting them? For every question the researchers answer, Gove says, 10 new ones come up.

The smallest fish he and Whitney found with plastic in its stomach was just a quarter inch long, about six millimeters. But the plastic fibers the fish are eating are smaller.

"They are less than one millimeter, things you can barely see with the naked eye," Whitney says. That is "the shocking part: The pieces we can't even see are the problem." □

In this sample, a blue plastic bag has begun to disintegrate. Two gnarled rope ends from a fishing net are collecting algae and other organisms. A striped mahi-mahi larva (center right), just under two inches long, turns away from the rope; an inch-long triggerfish (upper left), about 10 weeks old and almost of an age to head back to the reef, noses up to a triangular shard of white plastic.

In 2018 **David Liittschwager** photographed jellyfish for the October issue; staff writer **Laura Parker** wrote the June cover story on plastic trash.


LEONARDO'S

By CLAUDIA KALB

Photographs by
PAOLO WOODS AND
GABRIELE GALIMBERTI

ENDURING BRILLIANCE

500 years after his death, Leonardo da Vinci's stunning creativity and foresight in science, the arts, and engineering continue to amaze us.

The engineering for this gilded copper ball, completed during his apprenticeship with artist Andrea del Verrocchio in Florence, made a lasting impact on Leonardo da Vinci. Checking for lightning damage, Sandro Schievenin emerges from the sphere atop the Cathedral of Santa Maria del Fiore.

PREVIOUS PHOTO

Leonardo's "Mona Lisa" is believed to depict Lisa Gherardini, the wife of Francesco del Giocondo, a Florentine silk merchant. Every year, millions of visitors jostle for a view at the Louvre Museum in Paris. The painting, protected by a thick layer of glass that must be cleaned regularly, has never been restored.


TOSCANA

In Florence, Leonardo became known for his prodigious talent and received his first commissions. He was "an ornament, a symbol of power," says scholar Paolo Galluzzi. Here, Valter Conti, an Italian street artist, personifies Leonardo's celebrity status as he strolls toward the Uffizi Gallery to pose for photographs with tourists.

In an instant, centuries collide—a moment unlike anything I have ever experienced. I have come to Windsor Castle to see the queen's collection of Leonardo da Vinci drawings.

Outside the towering stone walls, tourists snap selfies and rummage through souvenir tea towels. Inside, past an arched gateway bedecked by gargoyles, Leonardo ushers me back to the Renaissance.

I can almost hear whispers of the artist as I gaze at a leather album bound in the late 1500s in the castle's stately print room. Gold embellishments adorn the volume's two-and-a-half-inch spine. The cover, stained and worn by the imperceptible fingerprints of generations past, reads: *Disegni di Leonardo da Vinci Restaurati da Pompeo Leoni* (drawings by Leonardo da Vinci conserved by Pompeo Leoni).

No one knows precisely how this album made its way to England, but its provenance is unambiguous: Leoni, an Italian sculptor, acquired Leonardo's drawings from the son of the artist's devoted pupil Francesco Melzi and mounted them into at least two volumes. By 1690, the Leoni binding, as it's known, had landed in the Royal Collection, teeming with 234 folio sheets and the peregrinations of Leonardo's inquisitive mind.

As Martin Clayton, head of prints and drawings for the Royal Collection Trust, lays out a selection of the pages—now separated into 60 boxes—the scope of Leonardo's subject matter soars into view: botany, geology, hydraulics, architecture, military engineering, costume design, geometry,

After a five-year restoration, Leonardo's "Adoration of the Magi" divulges brushstrokes, colors, and images long hidden under dirt and darkened varnish. The unfinished painting, commissioned in 1481, also shows evidence of the artist's thought process, including modifications he made as he worked. The painting is exhibited in a room at the Uffizi dedicated to Leonardo.

cartography, optics, anatomy. He sketched to make sense of unknowns, probing the enigmas of the universe with ink, chalk, and silverpoint.

The drawings are breathtaking in their lucidity. The most diminutive, a fragment smaller than a thumb, shows a female torso evoked in just a few muted strokes. The most iconic, rendered tenderly in red chalk and curved hatch marks, depicts a fetus curled up in the womb.

Everything is put to the test with visual precision: a study of drapery for the Madonna; mortars bombarding a fortress; the umbra and penumbra of shadow; a skull, a heart, a foot, and the sweep of the human face—from the radiance of Leda to the misshapen features of an elderly man.

"What you get most out of Leonardo's drawings in some of his sheets is this completely unfettered way of leaping between subject matter," Clayton says. "There's something tremendously exciting about seeing a mind working in this incredibly broad way."

An inherently curious note-taker and truth-seeker, Leonardo pursued knowledge voraciously. His to-do lists included jottings to "construct glasses to see the moon larger" and "describe the cause of laughter" as he sought answers to a cascade of questions: What's the distance from the eyebrow to the junction of the lip and the chin? Why are stars visible by night and not by day? How do the branches of a tree compare with the thickness of its trunk? What separates water from air? Where is the soul? What are sneezing, yawning, hunger, thirst, and lust?

Although his paintings are far better known, Leonardo's wealth of manuscripts and drawings lay bare the inner workings of his genius. His fertile mind—the range of hypotheses he tested, the intellectual, scientific, and philosophical journeys he launched—is evoked on every one of the 7,000 sheets preserved at Windsor, in libraries in Paris, London, Madrid, Turin, and Milan, and in the private collection of Bill Gates.

As the 500th anniversary of Leonardo's death is commemorated this year, the artist's notebooks are experiencing a renaissance of their own. Museums are mounting exhibitions of his sketches, and scholars are publishing new analyses, delving ever deeper into the full spectrum of his creations.

Most remarkably, pages from Leonardo's notebooks are finding their way into the hands of experts in the very fields Leonardo studied, from medicine and mechanical engineering to music. Reaching back centuries, they're reaping fresh insights, probing Leonardo's work to inform their own. Even as science, medicine, and technology have pushed past the boundaries of what we can do and how we can do it, Leonardo's notebooks reveal how much we still have to learn.

In the words of art historian and Leonardo scholar Martin Kemp: "Not one of his predecessors or contemporaries produced anything comparable in range, speculative brilliance, and visual intensity. And we know of nothing really comparable over succeeding centuries."

LEONARDO WAS BORN to unwed parents on April 15, 1452, near Vinci, a hill town in the rural Tuscan landscape between Florence and Pisa. Many believe his mother was Caterina di Meo Lippi, a local peasant. His father, Ser Piero da Vinci, held elevated status as a notary—a professional path that Leonardo would have been expected to follow had he not been born out of wedlock.

The town of Vinci proffered an inspiring backdrop for a boy with a capacious vision. From a terrace atop the village's 12th-century castle, the Tuscan landscape reveals itself today as it would have in Leonardo's

LEONARDO'S DRAWINGS

Thousands of sketches, observations, and queries (written in a distinctive backward script) showcase Leonardo's unceasing quest for knowledge. A vast number of the original pages have been lost. Those that remain, many compiled in notebooks, reveal a fluid interplay between his meticulous scientific studies and his monumental art.

LEONARDO

The Anatomist

Determined to understand every fiber in the body, Leonardo dissected animal and human cadavers. On this sheet, he rendered the bones and muscles of the arm, shoulder, and foot. Leonardo intended to publish an anatomical treatise but never did. Had he succeeded, he might have been recognized as the founder of modern anatomy, a distinction later given to Andreas Vesalius.

ROYAL COLLECTION TRUST/© HER MAJESTY QUEEN ELIZABETH II 2018


Lauren Van Scoy

THE ANATOMIST TODAY

Michael Grimaldi (center), director of drawing at the New York Academy of Art, has revered Leonardo since childhood. In a unique collaboration with the Drexel University College of Medicine in Philadelphia, Grimaldi's art students (in borrowed white lab coats) converge with Drexel's medical students (colored scrubs) to examine and sketch the human body. Dissections have far more impact than lectures, says Grimaldi.

Blurring the Lines

Leonardo didn't sign his paintings; collaboration was a common practice in his time, one that makes attribution a challenge today. But the 24 works at right are associated, some at least in part, with the master. Two of them, the *Mona Lisa* and *The Last Supper,* are among the world's most famous.

ca 1473
Tobias and the Angel

ca 1473-74
Annunciation

ca 1479-1481
Adoration of the Magi

ca 1483-1490
Virgin of the Rocks

ca 1485
Portrait of a Musician

ca 1501-07
Madonna of the Yarnwinder (Buccleuch Madonna)

ca 1503-1516
Mona Lisa

ca 1504-07
Salvator Mundi

TOTAL PAINTINGS 24

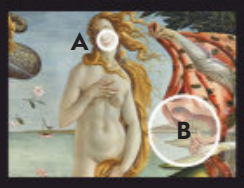
In a few cases, legal disputes and popular demand may have led Leonardo to create multiple versions of the same work.

- **5** With assistance
- **2** Contribution to work by Andrea del Verrocchio
- **4** Unfinished
- **6** Extent of Leonardo's contributions disputed
- **2** Lost

ARTISTIC ADVANCEMENTS

Expert sfumato

His knowledge of eye anatomy brilliantly informed a shading technique, not utilized by contemporaries like Botticelli, called sfumato. Blending softens outlines to create a three-dimensional effect.



Detail of *Birth of Venus,* Botticelli, 1484–86 (below)

A sense of space

A keen observer of nature, Leonardo successfully replicated the effect of atmosphere on distant objects. Hazy outlines of the landscape give the impression of distance on a two-dimensional canvas.

(A) Sandro Botticelli — Leonardo da Vinci

(B) Sandro Botticelli — Leonardo da Vinci

FERNANDO G. BAPTISTA, MONICA SERRANO, AND EVE CONANT, NGM STAFF; LAWSON PARKER. SOURCES: MARTIN KEMP, MATTHEW LANDRUS, UNIVERSITY OF OXFORD; MARTIN CLAYTON, ROYAL COLLECTION TRUST; PAOLO GALLUZZI, MUSEO GALILEO. CREDIT INFORMATION FOR THE PAINTINGS SHOWN HERE IS AT *NGM.COM/MAY 2019*.

ca 1475-76
Madonna and Child With a Carnation

ca 1476
The Baptism of Christ

ca 1476-78
Ginevra de' Benci

ca 1479-1480
Madonna and Child (Benois Madonna)

ca 1480-82
Saint Jerome in the Wilderness

ca 1490
Portrait of Cecilia Gallerani (Lady With an Ermine)

ca 1495-98
The Last Supper

ca 1495-1508
Virgin of the Rocks

ca 1496-97
Portrait of a Lady From the Court of Milan

ca 1498-99
Sala delle Asse*

ca 1501-07
Madonna of the Yarnwinder (Lansdowne Madonna)

ca 1506
The Battle of Anghiari
(copy by Peter Paul Rubens)

ca 1506-08
Leda and the Swan
(copy by Cesare da Sesto)

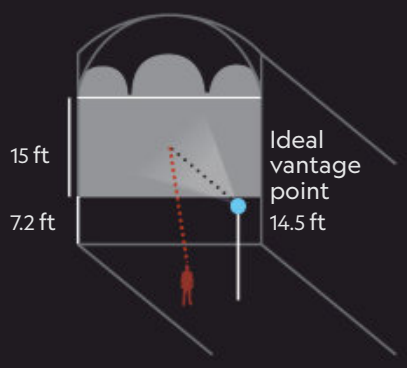
ca 1508-1516
Saint John the Baptist

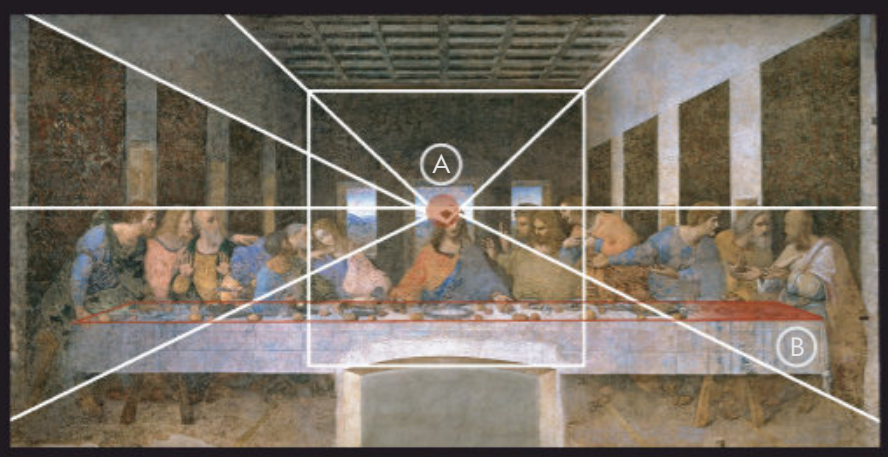
ca 1508-1517
Virgin and Child With Saint Anne

ca 1513-16
*Saint John the Baptist***

Fooling the eye

Leonardo started from an ideal vantage point, then used optical illusions to make other viewpoints seem equally ideal. The result was a mural that looked as if it were a natural part of the room.





(A) Leonardo crafted the perspective to draw the eyes to a single vanishing point, in this case directly on Jesus, to highlight the most important element in the composition.

(B) By playing with the vantage point, Leonardo made it possible for a viewer on the ground to see the table from above.

*THE IMAGE SHOWS A SMALL SELECTION OF THE MURALS PAINTED BY LEONARDO AND ASSISTANTS IN A SUITE OF ROOMS IN SFORZESCO CASTLE.
**THE ATTRIBUTES OF BACCHUS (AN IVY WREATH AND A STAFF, OR THYRSUS) WERE ADDED DURING THE 17TH CENTURY BY AN UNKNOWN ARTIST.

youth: olive groves, dusky hills, and a mountain range off Italy's west coast.

In Vinci, this vista is known as *orizzonti geniali,* or "genius horizons," says Stefania Marvogli of the Museo Leonardiano—an allusion to Leonardo and the geography that saturated his childhood. A patchwork of divergent terrains coming together to form a coherent whole, it reflects the connections Leonardo sought in nature: patterns that unify the cosmos.

Little is known about Leonardo's childhood. Records suggest that he lived with his grandparents in Vinci, where he received a rudimentary education. Sometime during Leonardo's adolescence, his father likely recognized his artistic abilities and showed his drawings to a client, the artist Andrea del Verrocchio, who agreed to take Leonardo on as an apprentice in his Florence workshop.

From the beginning, Leonardo upstaged his peers and soon his mentor, with whom he collaborated on religious paintings and on the copper ball that sits atop Brunelleschi's dome. Leonardo's earliest known independent work, a pen-and-ink landscape of the Arno Valley, dates to 1473, when he was 21. Within several years, he'd received his first commissions: an altarpiece for a chapel in the Palazzo della Signoria and the painting "The Adoration of the Magi" for a group of Augustinian monks.

Leonardo left few personal reminiscences of his own, but we have glimmers of the man. He was almost certainly gay—his lifelong companions were male, and he was twice accused of sodomy, though charges were

TODAY

Leonardo lacked tools to demonstrate his idea that air and water share properties. Here, Gary Settles of Penn State University uses schlieren, an imaging technique, to visualize the indiscernible: turbulence in the air.

LEONARDO

The Scientist

Leonardo not only observed and documented the natural world in his notebooks; he also launched experiments to understand the mechanics of how it worked. He was especially captivated by the properties of water. On this sheet he depicted the movement of water when disturbed by a barrier (top) and when falling from a sluice into a pool (bottom), forming vortices.

dropped in both cases. An animal lover, he bought caged birds at market and set them free. Left-handed and handsome, he wore rose-colored tunics and was admired for his singing voice, generosity of spirit, and social finesse. He would have been a very entertaining dinner guest, says Gary Radke, emeritus professor of art history at Syracuse University. "He wasn't one of these inscrutable, pondering, grousing geniuses."

Throughout his 46-year career, spent largely in Florence and Milan, Leonardo willed himself to knowledge, touched by an ever wandering eye and the determination to follow it. He studied Latin, collected poetry, and read Euclid and Archimedes. Where others embraced the perceptible, he scrutinized minutiae—geometric angles, the dilation of the pupil—bounding from one discipline to the next while seeking links between them. He sketched flowers and flying machines, designed war machines for his patron Duke Ludovico Sforza, crafted theatrical ornaments out of peacock feathers, and engineered a plan to divert the Arno between Florence and Pisa.

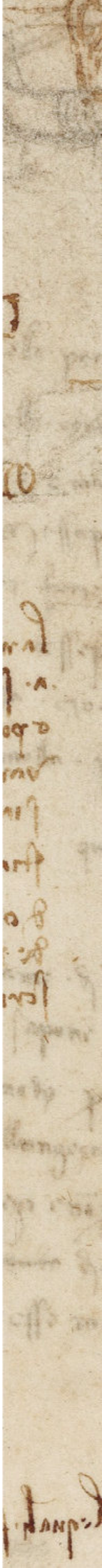
Leonardo documented everything in magnificent detail on the backs and corners of paper with tidy notes written in mirror script, from right to left. Some of these pages exist as loose sheets today; others have been bound into the volumes now known as notebooks or codices. There's no clear order, even on a single page, and similar themes often appear on different sheets completed years apart. All of this makes it hard even for scholars to keep up with the brisk tempo of his mind, Paolo Galluzzi tells me as he thumbs through reproductions of Leonardo's notebooks with a sense of wonder. Every time he made an observation, a question arose in his mind, which invariably led to another, says Galluzzi, director of Florence's Museo Galileo. "He went sideways."

It's difficult to grasp Leonardo's unparalleled ability to push past the work of his forebears. He did this by cross-examining his subjects and overturning his own verdicts. In the Codex Leicester, Leonardo investigates how water makes its way to mountaintops, ultimately rejecting his initial conviction that heat draws it upward. Instead, he realizes, water circulates through evaporation, clouds, and rain. "More important than discovering how mountain streams work was discovering how you would discover it," says biographer Walter Isaacson. "He helps invent the scientific method."

For Leonardo, the precepts of science—observation, hypothesis, and experiment—were critical to art. He moved fluidly between the two realms, grasping lessons from one to inform the other, says Francesca Fiorani, associate dean for the arts and humanities at the University of Virginia. His greatest gift was his ability to make knowledge visible, she says. "That's where his power is."

Nowhere is this more vivid than in Leonardo's study of anatomy. He dissected human cadavers, teasing out underlying musculature in three dimensions to see for himself how a leg bends or an arm cradles. Leonardo's contemporaries, including rival Michelangelo, studied muscles and bones to improve their artistic representation of the human body. "But Leonardo went beyond this," says science historian Domenico Laurenza, based in Rome. "His approach to anatomy was that of a real anatomist."

The scientific data Leonardo collected in his notebooks underlie every stroke of his paintbrush. His anatomical studies drilled down on the biology of facial expressions. Which nerve causes "frowning the brows" or "pouting with the lips, of smiling, of astonishment"? he queried in his notes. His analysis of light and shadow allowed him to illuminate contours with unmatched subtlety. He did away with traditional outlining,

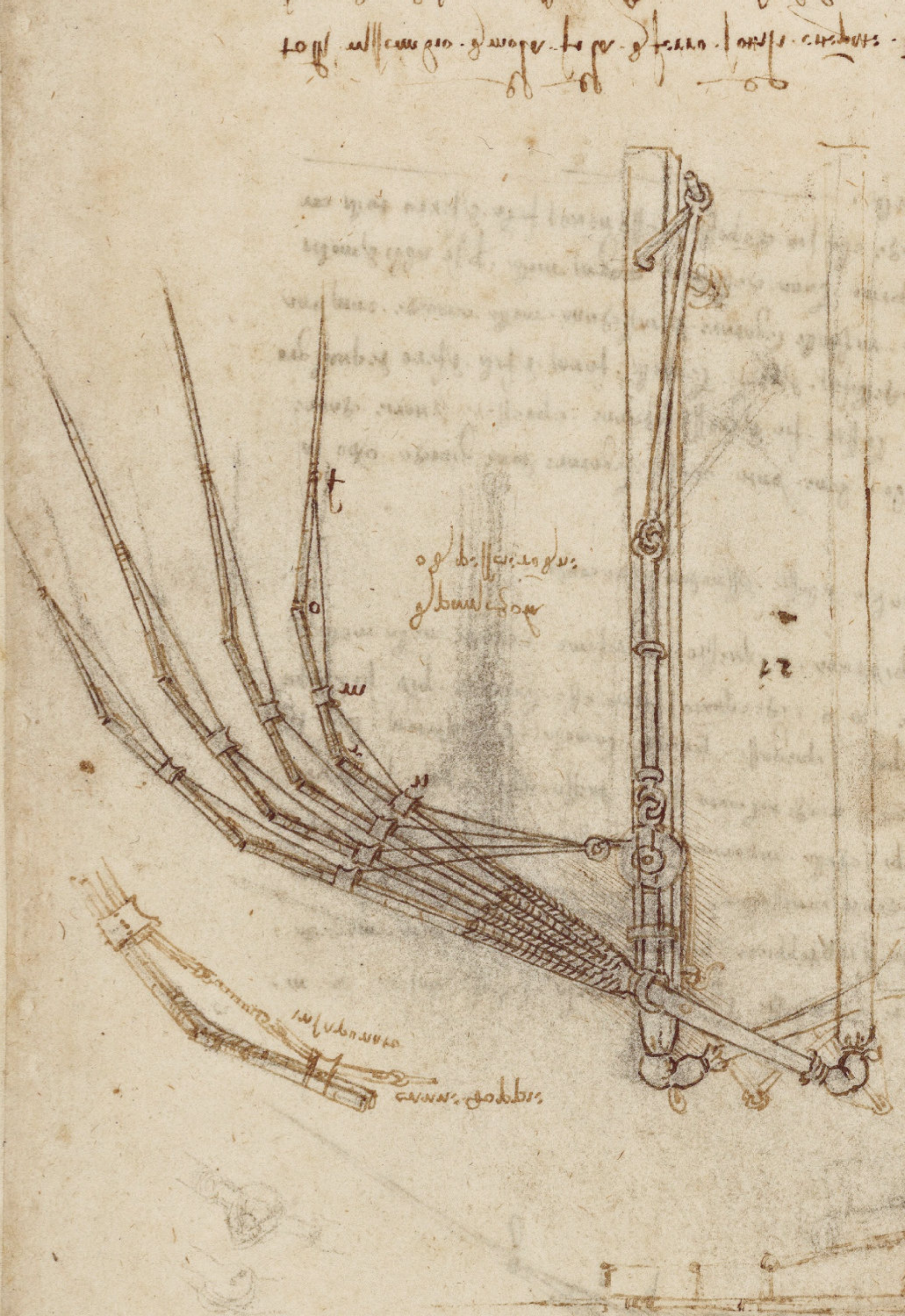


LEONARDO

The Engineer

Fascinated by the principles of engineering, Leonardo devised plans for bridges, buildings, and military equipment. Above all, he yearned to outline a flying machine for humans, and thus spent more than two decades studying animal flight. On a page from the Codex Atlanticus, he sketched a design for a mechanical wing.

VENERANDA BIBLIOTECA AMBROSIANA/BRIDGEMAN IMAGES



THE ENGINEER TODAY

Doctoral students in David Lentink's Stanford lab study the impact of airspeed and turbulence on their robotic bird, PigeonBot, inside a specially designed wind tunnel. The data collected will help them understand the mechanics of bird flight.

Flights of Imagination

Leonardo often found inspiration in nature. His observations of birds and bats helped refine his attempts, some more successful than others, to engineer flying machines. His quest to achieve manned flight occupied him for over two decades.

Flapping

Leonardo's early flying machines were mostly designed with wings, to be controlled by a pilot. But he found that humans can't flap hard enough to sustain flight. These machines wouldn't have worked.

His original sketch doesn't specify what the arms should do.

He noted that membranous, bony bat wings required less energy than feathered wings.

Horizontal pilot, ca 1488
Almost all body parts had a job. Hands and feet operated the wings; the pilot's rigged-up headband controlled the tail.

Manuscript B, f 75r

2 or 4 wings

Vertical pilot, ca 1495
In this design he experimented with standing positions: "Man is also possessed of a greater amount of strength in his legs than is required by his weight."

Leonardo's drawing

Codex Atlanticus, f 749r

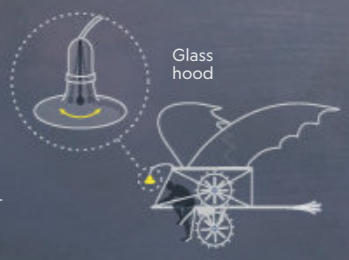
This design leverages powerful leg muscles to flap the wings via a system of pulleys operated by foot brackets.

Manuscript B, f 79r

AERIAL ADVANCEMENTS

Parachute, ca 1485
A British skydiver successfully tested Leonardo's parachute in 2000 but cut free before landing to avoid being crushed by the 187-pound design.

Inclinometer, ca 1485
When the ball is in the middle, the pilot knows he's horizontal to the ground. The bell jar blocks wind from moving the ball.



Aerial screw, ca 1489
He knew that when air is compressed it grows more dense. He designed this for festival entertainment; the concept was later used in helicopters.

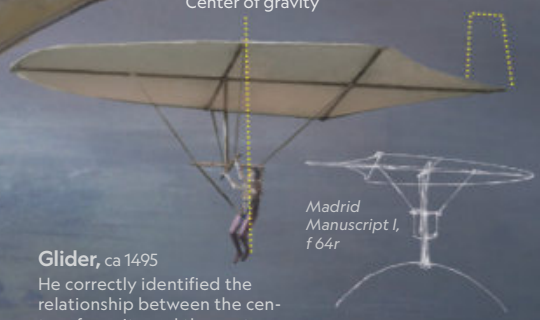
Gliding

Suspecting that humans lacked the power-to-weight ratio of birds, he shifted his studies to gliding, instead of flapping. These two designs, tested in modern times, worked with modifications.

Headband

Rudder

Center of gravity



Madrid Manuscript I, f 64r

Glider, ca 1495
He correctly identified the relationship between the center of gravity and the center of pressure in a glider, but his design needed a tail to work.

Mobile

Rigid

Mobile

When one leg is extended, it lowers one pair of wings; the hand crank raises the other.

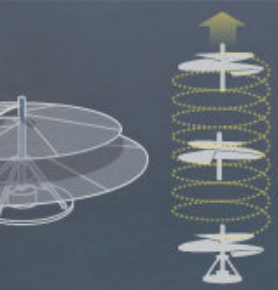
Horizontal flier, ca 1487-1490
The pilot's position is a close imitation of birds in flight. Many of Leonardo's designs were focused on a central element for wing movement.

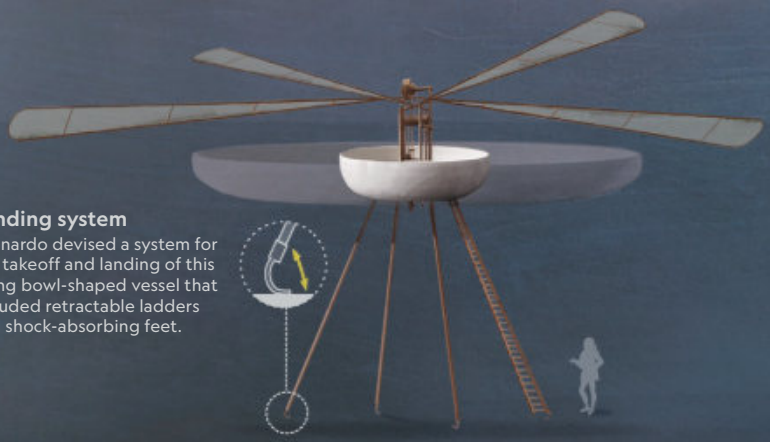
Manuscript B, f 80r

Flying vessel, ca 1488-89
Many of his designs weren't at first drawn to scale. He sketched this bowl-shaped vessel, later providing dimensions for a larger version.

Codex Atlanticus, f 846v

Glider, ca 1495-96
The central section of the wings, close to the pilot, was rigid. Flexible outer parts of the wings, controlled with cables, aided in pitch, navigation, and banking.





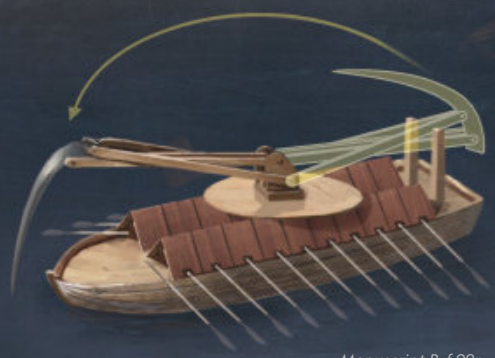
Landing system
Leonardo devised a system for the takeoff and landing of this flying bowl-shaped vessel that included retractable ladders and shock-absorbing feet.

Stroke

Flaps, ca 1489
To minimize resistance and maximize thrust, "skin" flaps allowed air through the wings on the upstroke but closed on the downstroke.

The Art of War

Leonardo, a pacifist and likely a vegetarian, called war a "beastly madness." Yet the artistic genius was drawn into weapon design by his patrons and the creative challenge of imagining tools that amplified human strength. Most of his weapons were very ambitious—and were never built.



Manuscript B, f 98r

Sail shredder, ca 1484-86
A scythe on a wooden pole rotates 360 degrees and—when activated by rowers—can tear through the sails and masts of enemy ships.

Armored carriage, ca 1487-1490
A fresh take on a concept from the Middle Ages, Leonardo's tank had new movement systems and a ring of cannons for a 360-degree attack.

Wheels

Cranks

Eight men would turn the cranks to move the wheels. A turret helped them aim.

Giant crossbow, ca 1485-1490
More than 30 preparatory drawings illustrate Leonardo's ambitions for this bow that would shoot cannonballs. It was built, but not in his lifetime.

1. The bow is aimed left and right by lifting the back and pivoting the front wheels.

2. Capstans rotate a gear connected to a screw that pulls back the ropes and trigger.

3. Men load the bow with a 100-pound stone, and activate the trigger by a lever or a hammer blow.

Capstans

Screw

Trigger

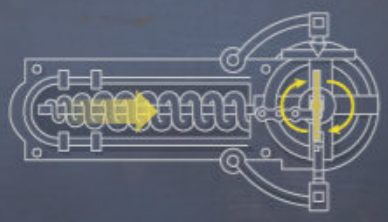
Stone

Width: 82 ft

MECHANICAL ADVANCEMENTS

Oval projectiles, ca 1500-1505
Leonardo knew that a cannonball's trajectory is influenced by the air around it. To improve targeting, his cannonballs were pointed, as modern bullets are.

Automatic striker, ca 1497-1500
The wheel lock ignites gunpowder on varying weapons. A trigger spins a wheel via a spring; the spinning wheel scrapes against stone, sparking heat to light the powder.



CREDIT INFORMATION FOR SKETCHES BY LEONARDO IS AT *NGM.COM/MAY2019*.

FERNANDO G. BAPTISTA, MONICA SERRANO, EVE CONANT, NGM STAFF; LAWSON PARKER

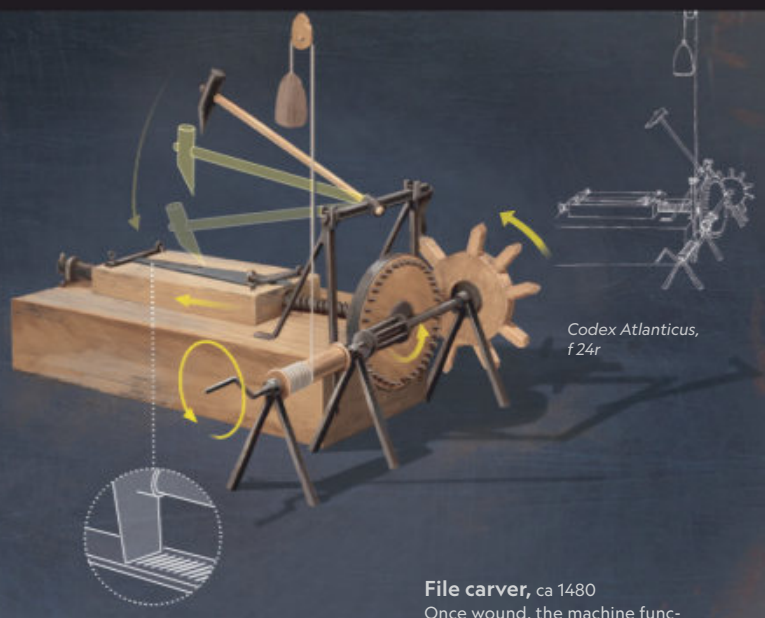
SOURCES: MARTIN KEMP, MATTHEW LANDRUS, UNIVERSITY OF OXFORD; PAOLO GALLUZZI, DOMENICO LAURENZA, MUSEO GALILEO; LEONARDO3; MUSEO NAZIONALE SCIENZA E TECNOLOGIA

Master in Motion

Leonardo's innovations were often conceptual experiments, developed for patrons or for his own amusement. His engineering genius, however, could be found in countless sketches that sought to improve upon such elemental, everyday fixtures as the screw, the wheel, and the spring.

British Museum

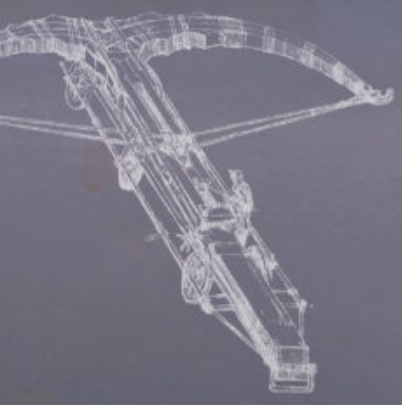
Art includes a flaw: In Leonardo's concept sketch, wheels would turn in opposite directions, preventing motion.



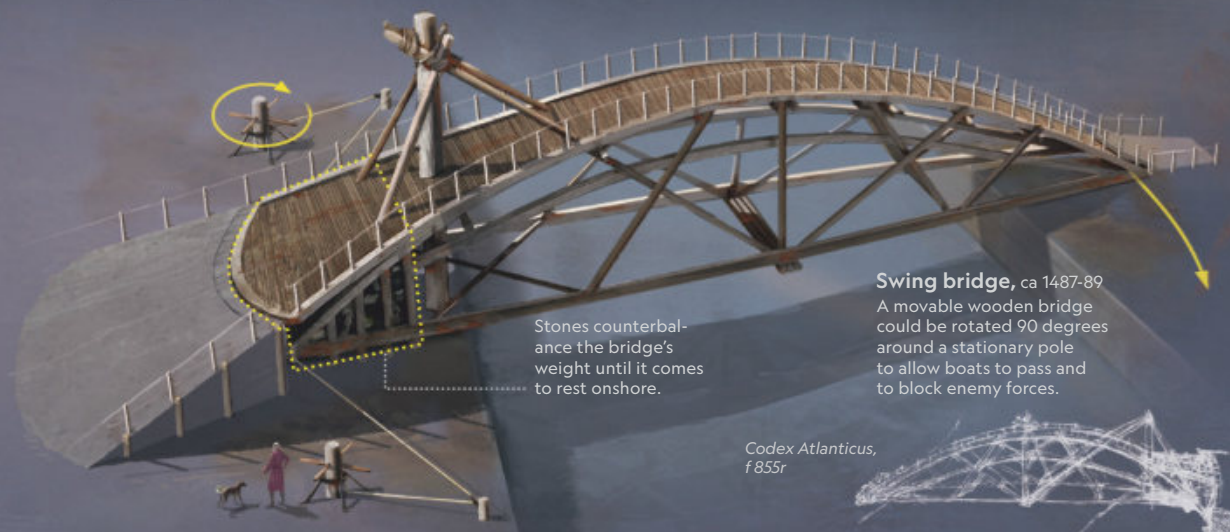
Codex Atlanticus, f 24r

The hammer, with sharp and changeable heads, leaves cross-mark incisions.

File carver, ca 1480
Once wound, the machine functions automatically. A hammer is lifted by a wheel, then dropped onto a file-shaped piece of metal as it's pushed forward by a screw.



Codex Atlanticus, f 149 Br

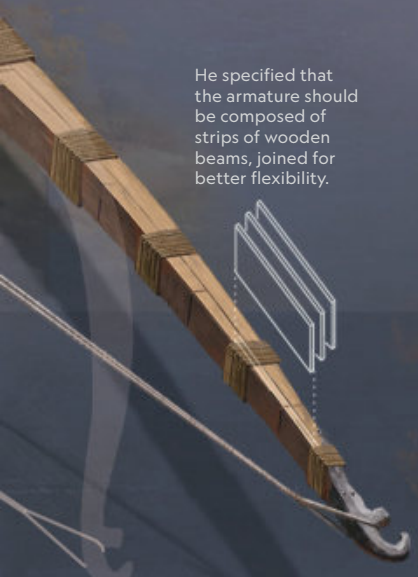


Stones counterbalance the bridge's weight until it comes to rest onshore.

Swing bridge, ca 1487-89
A movable wooden bridge could be rotated 90 degrees around a stationary pole to allow boats to pass and to block enemy forces.

Codex Atlanticus, f 855r

He specified that the armature should be composed of strips of wooden beams, joined for better flexibility.

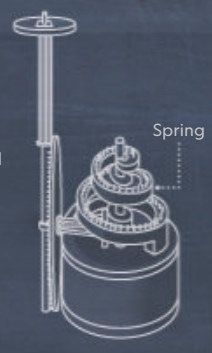


Range of designs
He invented or reimagined a seemingly endless array of machines.

Crane | Self-propelling cart | Walk-on-water shoes | Theater stage set | Vertical drill | Hydraulic saw

Roller bearing, ca 1497
He grasped that friction limits the transfer of motion. His roller bearings were an ingenious method to reduce friction between surfaces.

Spiral gear, ca 1499
Leonardo conceived of a spiral gear that would keep a spring powerful throughout its unwinding, an issue that had been problematic in clocks.



instead softening the edges of figures and objects in a technique known as sfumato. Optics and geometry led to a sophisticated sense of perspective, exemplified in "The Last Supper." Acute observations allowed him to depict emotional depth in the people he painted, who appear sentient rather than stiff.

Leonardo's inventiveness, however, came at a price. He irked his patrons with incessant delays, and many of his works went unfinished, including "The Adoration of the Magi" and "The Virgin and Child With Saint Anne." Scholars have attributed this to his exuberance for new subjects and his perfectionism. It was also because the challenge of doing outweighed the expectation of getting it done. For Leonardo, it's all about process, says Carmen Bambach, curator of drawings and prints at the Metropolitan Museum of Art in New York. "It's not really about the endgame."

Indeed the more knowledge Leonardo acquired through the studies in his notebooks, the more difficult it became to see a finish line in his art. "As he kept painting," Bambach explains, "he understood that you could create such infinitesimal gradations of tone and transition from the highest, most intense highlight to the deepest shadow." X-ray analyses of Leonardo's work reveal copious revisions, known as pentimenti. Infinity became a very real concept that took on practical implications: There was always more to learn. "In many ways, intellectually, this is an unending process," she says.

This may help explain why Leonardo never published his notebooks. He intended to complete treatises on many subjects, including geology and anatomy. Instead his sketches and manuscripts were left to his faithful companion Melzi to sort through. In the decades after Leonardo's death, two-thirds to three-quarters of his original pages were likely pilfered or lost. It was not until the late 18th century that most of the surviving pages began to be published—more than 200 years after he died. As a result, Laurenza says, "we know very little about Leonardo's legacy as a scientist."

Leonardo's inquiries, postulations, and discoveries were entrusted to those who followed. Centuries later we're still catching up with him.

THE LEGACY of Leonardo's notebooks is palpable today. J. Calvin Coffey, foundation chair of surgery at the University of Limerick's Graduate Entry Medical School in Ireland, was conducting research a number of years ago when he made an astounding discovery: An observation by Leonardo, circa 1508, confirmed a theory he was trying to validate. Coffey studies the mesentery, a fan-shaped structure that connects the small and large intestines to the back wall of the abdomen. Since the publication of *Gray's Anatomy* in 1858 (then called *Anatomy: Descriptive and Surgical*), students have been taught that the mesentery is composed of several separate structures. But while performing an increasing number of colorectal surgeries, Coffey had begun to suspect that the mesentery was one continuous organ.

As he and his colleagues homed in on the structure's anatomy to prove this hypothesis, Coffey found a drawing by Leonardo depicting the mesentery as an uninterrupted structure. Coffey remembers the moment distinctly. Initially, he glanced at it and turned away. Then he looked again.

"I was absolutely astonished at what I saw," he says. "It correlated exactly with what we were seeing. It's just an absolute masterpiece."

In one overview of his team's findings, published in 2015, Coffey included Leonardo's drawing and credited him in the text: "We now know that da Vinci's interpretation was correct." Coffey shows a slide of Leonardo's sketch in his scientific presentations, marveling at his ability to dissect the organ in

LEONARDO

The Inventor

Leonardo filled his notebooks with inventions that were never built, including this apparatus designed to allow divers to breathe underwater. A pacifist, Leonardo stated that he wouldn't divulge how to make his underwater devices "by reason of the evil nature of men." He feared that such contraptions might be used to destroy ships and kill the people aboard.

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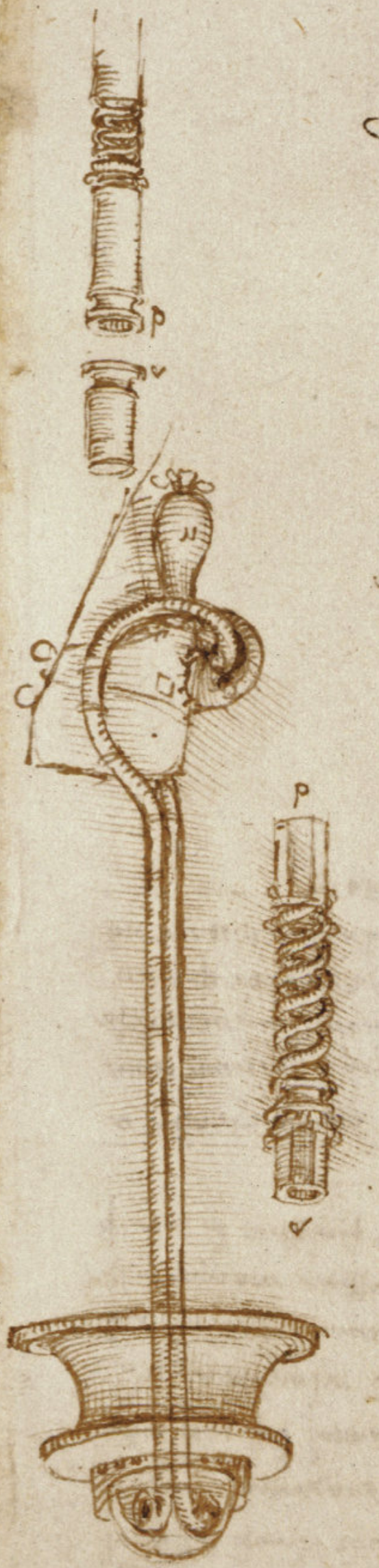
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THE INVENTOR TODAY

Though rudimentary, Leonardo's underwater designs foreshadowed equipment used by the military today. In the port city of Messina a member of the Italian Navy's special forces trains in a pressurized diving suit that can reach depths of almost a thousand feet.

its entirety, a feat complicated by the complex layering of the structure. "He was so honest in his interpretation of nature and biology," Coffey says. "Even today, you will have surgeons who will not be able to replicate what he did."

Leonardo's visual acuity was driven by his abiding faith in nature's design, whether a tree root or a hippopotamus. Human ingenuity, he wrote, "will never devise any inventions more beautiful, nor more simple, nor more to the purpose than Nature does; because in her inventions nothing is wanting, and nothing is superfluous." Every artery, every tissue, every organ existed for a purpose—a revelation that changed the course of Francis Charles Wells's career.

Wells, senior cardiac surgeon at Royal Papworth Hospital in Cambridge, England, happened upon an exhibition of Leonardo's anatomical drawings at the Royal Academy of Arts in the Piccadilly neighborhood of London in 1977. The entry fee was one British pound; the payoff, immeasurable. "It just blew me away," he says.

Wells was stunned by the scope of the artist's investigations. After dissecting the body of a 100-year-old man, Leonardo presented the first description of atherosclerosis in medical history. "This coat on the vessels acts in man as it does in oranges," he wrote, "in which as the peel thickens so the pulp diminishes the older they become."

His research on heart valves, Wells's specialty, was just as prescient. To understand how they work, Leonardo designed a glass model of the aortic

LEONARDO

The Musician

A gifted musician, Leonardo researched acoustics, sang, and improvised melodies on his lira da braccio (a bowed Renaissance stringed instrument). He also designed a range of musical instruments, including drums, bells, and woodwinds. Here, he brainstormed ideas for a keyboard-string combination known as a viola organista. Sławomir Zubrzycki, who later built a viola organista, says Leonardo "designed a perfect instrument."

VENERANDA BIBLIOTECA AMBROSIANA/BRIDGEMAN IMAGES

TODAY

At home in Kraków, Poland, Zubrzycki plays the viola organista he crafted, inspired by Leonardo. A pedal activates four circular bows covered in horsehair, which rub against the strings to create a melodious sound.

AREZO

AMBRA · FL

GRASSINA · FL

GREVE · FL

VERGIGNO · FL

GHIENNA · FL

PESA · FL

ARBIA · FL

STAGGIA · FL

ELSA · FL

SELLA · FL

CIECINA · FL

FENA · FL

OMBRON · FL

SIENA

LEONARDO

The Cartographer

Leonardo was commissioned to design maps for civil and military purposes. This depiction of a region in Tuscany demonstrates his ability to communicate geographic information through artistry. Centuries before aerial photography and high-tech programming revolutionized cartography, Leonardo created bird's-eye views of cities and landscapes.

valve filled with water and grass seeds, allowing him to conceptualize patterns of blood flow and how the valves open and close, details of which were finally confirmed in the 1960s.

More than anything, Leonardo's sketches opened Wells's eyes to the exquisite logic of the heart's structure and mechanics—not just what the organ looks like but also why it evolved the way it has. One autumn morning Wells stands over a patient's open chest in his Papworth operating theater and motions me closer.

"See it? It's astonishing," he says, pointing to the mitral valve. "Think of the complexity that the body has to go through to make this valve." Wells's surgical approach is guided by the maxim he learned from Leonardo: Each part of the valve's complex makeup—its leaflets, cords, and papillary muscles—is meant to be there, designed to sustain the forces thrust upon it.

This has fundamentally shaped the way Wells fixes ailing valves. "You see that little thing in my forceps? That's the ruptured cord," he says. "That's the source of the problem." Wells could opt to remove the entire valve and replace it with an artificial model, an approach favored by many surgeons.

Instead I watch as he painstakingly replaces every cord with Gore-Tex sutures, preserving as much of the original structure as he can. Leonardo could not predict a surgical approach, but he taught Wells to look carefully, to stop and think, and to fully embrace the valve's inherent and masterful ability to do its job, a capability Wells seeks to retain in every cardiac operation he performs. "That was the paradigm shift," says Wells, who collected his insights in a 256-page book, *The Heart of Leonardo.*

A continent away, Leonardo's Codex on the Flight of Birds has permeated the Stanford University Bio-Inspired Research and Design (BIRD) lab of David Lentink, a biologist and mechanical engineer. When I visit, Lentink hands me a piece of paper with queries explored by Leonardo that he and his 10 graduate students are still trying to answer: How does wing motion in air result in thrust? How do birds' muscles control the

THE CARTOGRAPHER TODAY

The Virginia-based National Geospatial-Intelligence Agency uses sophisticated technology to collect data about physical features. NGA maps provide critical information during disasters. Here, screens show high-resolution images of Antarctica.

flapping of their wings? How do birds glide? "All his questions are still relevant," Lentink says.

Lentink and his team have access to high-tech tools that even Leonardo couldn't have dreamed up. Sensors and high-speed photography allow them to measure the amount of lift that birds generate in flight. A nearly six-foot-long test section of a wind tunnel, which Lentink custom designed, simulates smooth air as well as turbulence, providing clues about how birds' wings change shape during vastly different wind conditions.

One of the lab's standout projects is a mechanical bird called PigeonBot, which has feathered wings crafted by Laura Matloff and a radio control system run by fellow grad student Eric Chang. Matloff used an x-ray microscope, capable of measuring one-millionth of a meter, to determine the characteristics of the feather surfaces and interactions between adjacent feathers. The skeleton and pin joints, which attach the feathers, were made on a 3D printer. PigeonBot is equipped with an accelerometer, a gyroscope, a barometer, an airspeed sensor, a GPS, compasses, and radio transceivers that transmit flight information to a laptop.

I meet the pair one cloudy morning in the hilly brush near Stanford for a test flight. As Chang says, "Ready!" Matloff thrusts the robot into the air; we watch it fly at about 10 meters a second until Chang brings it in for a landing. PigeonBot isn't just for show. Reverse engineering a bird allows scientists to study flight mechanics in a step-by-step process and better understand the function of each body part—something Leonardo couldn't do. Modern engineering may one day reward Leonardo's ardent curiosity with answers to the mysteries he pursued. "I think we'll get there," says Lentink.

JUST AS LEONARDO'S notebooks brim with bursts of clarity, they also include more tentative musings that flicker with possibility. Drawings contained in the Codex Atlanticus and several smaller notebooks prompted Polish pianist Sławomir Zubrzycki to investigate. He hungered to hear Leonardo's music.

Among his many pursuits, Leonardo improvised melodies on the lira da braccio, a Renaissance-era stringed instrument, and studied the intricacies of acoustics and musical design in his notebooks. In 2009 Zubrzycki found himself transfixed by sketches for a viola organista, a keyboard instrument with bowed strings. Captivated by the possibility of one instrument fusing two musical families, Zubrzycki set out to build it.

None of Leonardo's drawings offer a detailed blueprint. For four years Zubrzycki spent five hours a day researching and formulating his design. He tested wood samples, resolved that he needed 61 keys, and puzzled out how to build four circular bows covered in horsehair that could rub against strings to create music. As he brought the instrument to life, Zubrzycki drew on the same vital force that drove Leonardo: his imagination.

The result is spectacular. Painted in vivid blue with a red interior, Zubrzycki's gracefully crafted viola organista combines the polyphonic capacity of a keyboard—allowing it to play multiple melodies at once—with the sensitivity and emotive range of strings. In music, as in everything else, Leonardo was never satisfied with the norm.

"He was interested in looking for the next possibility," Zubrzycki says.

One summer evening, dressed in a formal waistcoat and polished black shoes, he sits down to play a concert of Renaissance music at Kalmar Castle on the southern coast of Sweden. Although his viola organista looks like a baby grand piano, it performs like a full-bodied string ensemble.

Resounding and joyful, the rich complexity of its sound evokes the luminescence of Leonardo's paintings—a musical sfumato with soft edges and lingering tones.

Leonardo ranked music as second only to painting, higher even than sculpture, describing it as *"figurazione delle cose invisibili,"* the shaping of the invisible. For the hundred-plus people in Zubrzycki's audience, such an exalted moment occurred in a castle as the sun began to set over the Baltic Sea, when a few scribbles in Leonardo's notebooks morphed into music.

Ute Goedecke and Per Mattsson, Swedish Renaissance musicians, were deeply impressed and moved by Zubrzycki's performance. Leonardo "would have loved to see that somebody took his idea to the next stage," says Goedecke, "and made something real out of it."

LEONARDO'S FINAL FORAY, in the fall of 1516, took him to Amboise, France, where King Francis I, an enthusiastic admirer, offered him a stipend and the freedom to create whatever he wished. At 64, Leonardo moved into a modest château, now known as Clos Lucé, with his many drawings and the three paintings he never parted with—"Saint John the Baptist," "The Virgin and Child With Saint Anne," and the "Mona Lisa."

From his bedroom window, Leonardo could see the king's castle. Outside, the colors and light of the Loire Valley echoed the vistas of his childhood. During his years at Clos Lucé, Leonardo designed hydraulics for the kingdom, sketched plans for a new royal residence, and staged joyful celebrations for the king. Amid it all, he enjoyed simple pleasures: He ate soup.

Before he died on May 2, 1519, at the age of 67, Leonardo completed a series of deluge drawings, depicting cataclysmic billows of wind and water. Rampaging vortices, executed mostly in black chalk, they surge with urgency and tumult. In the end Leonardo turned his eye, as always, to nature.

Today Clos Lucé is a living monument to Leonardo, set in a sprawling park filled with sage and other plants Leonardo sketched. Children play on a parabolic swing bridge and a tortoiseshell-like armored tank, derived from Leonardo's notebooks. Walking the grounds one sunlit day, François Saint Bris, Clos Lucé's director, says he hopes the place where Leonardo spent his final years will inspire next generations.

It's a goal many share. New research is providing fodder for future scholars. Laurenza and Kemp have collaborated on a fresh analysis of the Codex Leicester, which reveals that it may have influenced the birth of modern geology. And after more than two decades of meticulous research about Leonardo's life and work, the Met's Bambach is publishing a four-volume opus, *Leonardo da Vinci Rediscovered*.

Leonardo's notebooks are starting to make their way to the greater public too. Galluzzi is spearheading an elegant searchable database of the Codex Atlanticus, the largest notebook. Isaacson imagines a day when all of them will be fully translated and digitized by a single international consortium. "Then we will see Leonardo in all of his glory," he says.

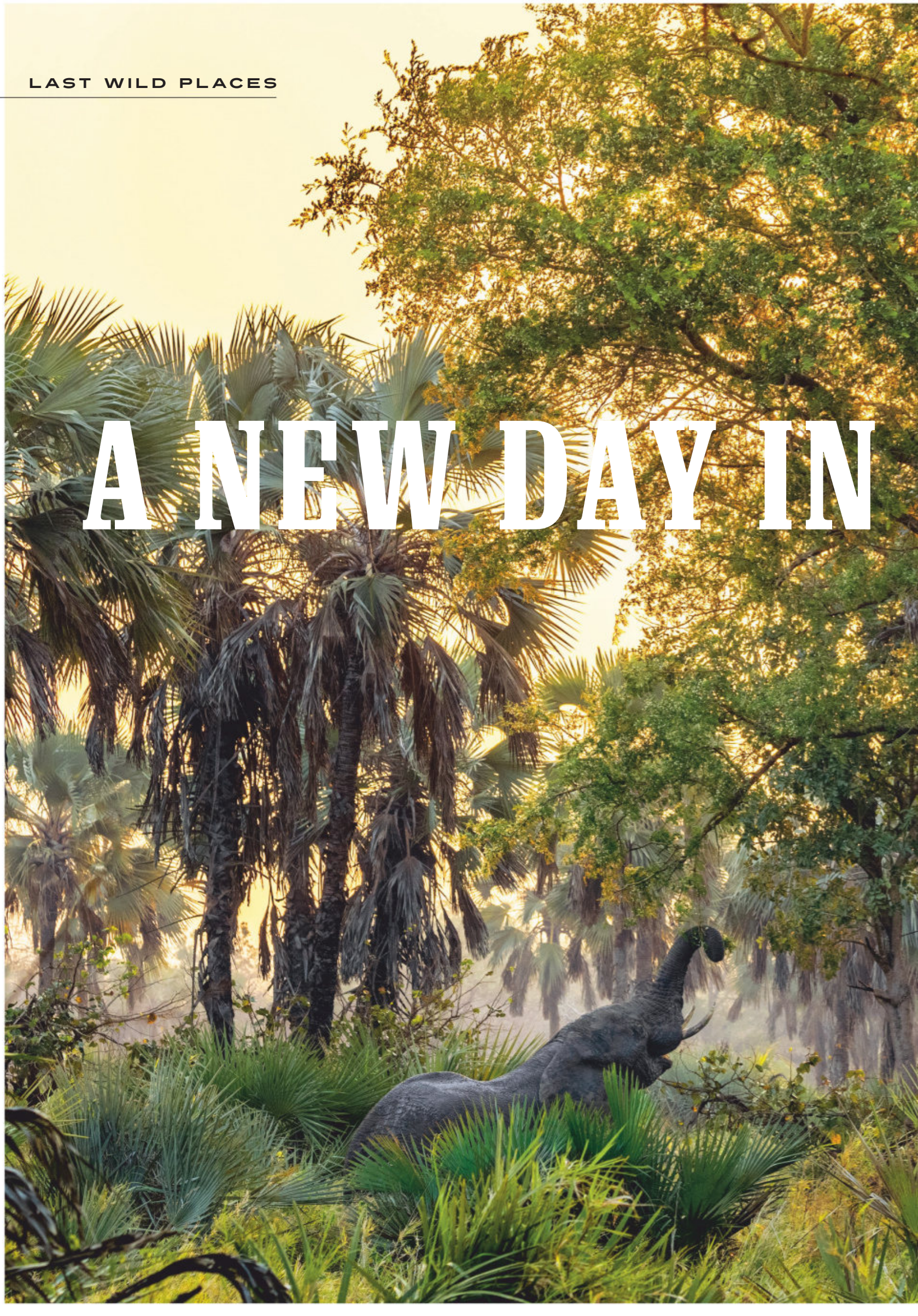
Just as Leonardo saw no end to his pursuit of knowledge, his notebooks are poised for rediscovery and posterity.

"I keep thinking I've finished with Leonardo," says Kemp, who has studied and written about him for five decades. "He keeps coming back." ▯

In the famed Carrara quarries in northwest Italy—the place Michelangelo visited five centuries ago to select marble for statues—stands a sculpture of Leonardo. This figure, made by Torart, an Italian company specializing in robotic sculpting, is a replica of a 19th-century statue that keeps watch under the portico of the Uffizi Gallery. Artisans use computer-generated blueprints, robotic scalpels, high-pressure water jets, and their own handiwork in reproductions and original pieces.

Claudia Kalb writes about the science and culture of genius. This is her third collaboration with photographers **Paolo Woods** and **Gabriele Galimberti,** who live in Florence. Their cover story on Picasso appeared in the May 2018 issue.

A NEW DAY IN



By **DAVID QUAMMEN**

Photographs by
CHARLIE HAMILTON JAMES

MOZAMBIQUE

WILDLIFE IN GORONGOSA NATIONAL PARK, DECIMATED BY YEARS OF CIVIL WAR, IS REBOUNDING. THE ANIMALS' FUTURE DEPENDS ON PROVIDING HOPE FOR THE PEOPLE WHO LIVE NEARBY.

Cradled in the southern end of Africa's Great Rift Valley, Gorongosa's 1,500 square miles span mountainsides, plateau forests, escarpment canyons, palm savannas, and wetlands. The Bunga inselbergs—ancient nubs of volcanic rock left behind by the erosion of softer surroundings—punctuate the sweep of forest.

PREVIOUS PHOTO

A male elephant grabs an evening snack in Mozambique's Gorongosa National Park. Most of the park's elephants were killed for their ivory, used to buy weapons during the nation's 15-year civil war, which ended in 1992. With poaching controlled, the population is recovering.

African wild dogs were lost entirely from Gorongosa during the war. With some prey populations booming, the park needs its native predators. A pack of 14 wild dogs from South Africa, released in 2018, now helps balance the ecosystem.

White-faced whistling ducks take flight above a company of pelicans and storks wading in Gorongosa's Sungué River, which feeds the park's Lake Urema. Even in the dry season, the lake and its tributary channels harbor abundant birdlife.

LAST WILD PLACES

Gorongosa National Park is a conservation partner of the National Geographic Society's Last Wild Places initiative.

ON A WARM MORNING at the end of the dry season, early November, a red and black Bell Jet Ranger helicopter raced eastward above the palm savanna of Mozambique's Gorongosa National Park.

Mike Pingo, a veteran pilot originally from Zimbabwe, controlled the stick; Louis van Wyk, a wildlife-capture specialist from South Africa, dangled halfway out the right rear side holding a long-muzzle gun loaded with a drug-filled dart. Seated beside Pingo was Dominique Gonçalves, a young Mozambican ecologist who serves as elephant manager for the park.

More than 650 elephants now inhabit Gorongosa—a robust increase since the days of the country's civil war (1977-1992), when most of the park's elephants were butchered for ivory and meat to buy guns and ammunition. With the population rebounding, Gonçalves wanted a GPS collar on one mature female within each matriarchal group.

Gonçalves picked a target animal from a group running amid closely spaced palms, and Pingo took the helicopter in as low as the trees permitted. Ten elephants—adult females, small calves at their sides, subadults also staying close—fled the throbbing din of rotors. Van Wyk, forced to make a longer shot than usual, nevertheless put his dart into the chosen female's right buttock.

Pingo landed, and the other two jumped out, clambering through trampled grass toward the sedated elephant. Moments later a ground team arrived with heavier supplies, technical helpers, and an armed ranger. Gonçalves placed a small stick in the end of the elephant's trunk, propping

Jacinta Sainet Miquirosse tends a cook fire at her home on Mount Gorongosa. For decades, communities on the mountain have scraped out a meager living by cutting trees to grow corn, their staple crop. Now Miquirosse and her neighbors are part of a park project that adds coffee as a cash crop to their farms, helping to reforest the mountain with shade trees in the process.

it open for unimpeded breath. The animal, sprawled on her right side, began snoring loudly. One technician drew a blood sample from a vein in the left ear. Another helped van Wyk scooch the collar under the elephant's neck.

Gonçalves, wearing medical gloves, took a swab of saliva from the animal's mouth and a rectal swab from the rear, sealing them both into vials. She pulled a long plastic sleeve onto her left arm and reached deep up the elephant's rectum, bringing out a handful of fibrous, ocher poop that would be used to analyze the elephant's diet. The elephant's great flank heaved up and down gently in rhythm with the trombonic susurrus from her trunk.

"Louie, can you tell if she's pregnant?' Gonçalves asked.

"She's due soon," van Wyk said, noting the watery milk leaking from the elephant's distended breasts.

The growth of the elephant population is only part of the encouraging news from Gorongosa. Most of the big fauna, including lions, African buffalo, hippos, and wildebeests, are vastly more numerous now than in 1994, shortly after the war. In the realm of conservation, where too many indicators herald gloom and despair,

This article is supported by the Wyss Campaign for Nature, which is working with the National Geographic Society and others across the globe to help protect 30 percent of our planet by 2030.

success on such a large scale is rare.

Van Wyk finished fitting the collar and Gonçalves packed up her samples. Van Wyk injected a wake-up drug into an ear vein, and the crew backed off to a safe distance. After a minute, the elephant stood, gave her head a groggy shake, and strode away to rejoin her group. Tracking data from the collar will tell Gonçalves and her colleagues how the elephants move across the landscape—and alert them when the group is crossing a park boundary toward a farmer's field, so the farmer can take steps to save the crops.

This is how it's done in the Gorongosa Restoration Project, a partnership launched in 2004 between the Mozambican government and the U.S.-based Gregory C. Carr Foundation. For elephants and hippos and lions to thrive within a park boundary, you need to ensure that the humans who live outside the boundary thrive too.

STRETCHING ACROSS a floodplain at the south end of Africa's Great Rift Valley, encompassing savannas, woodlands, wetlands, and a wide pan of water called Lake Urema, Gorongosa was once a hunting reserve: Portuguese colonial administrators established it in 1921 for their sporting pleasure by removing the people who once shared the landscape with wildlife. In 1960, when first designated a national park, it harbored about 2,200 elephants, 200 lions, and 14,000 African buffalo, as well as hippos, impalas, zebras, wildebeests, eland, and other iconic African fauna.

But its remoteness became its undoing. In the ruinous 15-year civil war that followed independence in 1975, Gorongosa served as a refuge for the right-wing RENAMO, or Resistência Nacional Moçambicana, rebel forces who received military support from neighboring Rhodesia (now Zimbabwe) and South Africa. When government troops came to challenge them, there was fighting on the ground, rocket shelling of the park headquarters, carnage across the savanna. In addition to the elephant slaughter, thousands of zebras and other big animals were killed for food or trigger-happy amusement. A cease-fire halted the war in 1992, but poaching by professional hunters continued, and people in surrounding communities set traps for whatever edible animals remained. By the turn of the century, Gorongosa National Park had been wrecked.

Circumstances were just as grim on the lands surrounding the park. About 100,000 people

lived in what planners now call the buffer zone—mostly families growing corn and other subsistence crops, barely able to feed themselves, their children shorted on education and health care.

When the soil tired and the corn failed to thrive, the farmers would cut forest, burn the slash, and try again on a new patch. Eventually their cutting and planting expanded from the lower slopes of Mount Gorongosa—a granite massif that looms 6,112 feet above the western boundary of the park—to the higher, wetter zones. Once topped by thick rainforest, the mountain is the source for the Vunduzi River, which carries water to the park and its rich floodplain. By the start of the 21st century, large swaths of forest on the mountain and elsewhere throughout the 2,000-square-mile buffer zone had been stripped away.

The beginning of the end to this cycle of desperation and loss came in 2004, when the president of Mozambique, Joaquim Chissano, visited Harvard University for a lecture at the invitation of an American named Greg Carr. In 1986 Carr and a friend had created a company called

LEFT

Gorongosa Girls' Clubs, such as this one in the farming village of Mussinhá, meet daily before or after school in settlements around the park, engaging more than 2,000 girls. Club activities focus on literacy, reproductive health, and play—and help keep girls in school. Their songs promote education, children's rights, and ways to avoid HIV/AIDS.

BELOW

The park's ranger force—261 at present—includes 11 women, and more are being recruited. Patrols such as this one get orders via text each morning and make sweeps, scouting for snares and deterring poachers.

Late in the dry season, a remnant pool in the Mussicadzi River channel attracts a mob of hungry birds, including storks, egrets, and hammerkops, along with a couple of thirsty waterbuck. Gorongosa's avian richness swells further in the wet season, when nomads arrive to feed.

MEASURING SUCCESS

5,867

SPECIES DOCUMENTED

In addition to aerial counts, the park began to conduct annual biodiversity surveys in 2013 to catalog all of its species. Notable finds: the "Chewbacca bat" and a cave-dwelling frog.

4,800

VISITORS IN 2018

Renewed conflict from 2014 to 2016 in central Mozambique halted what had been a rise in visitor numbers. With a tentative cease-fire, tourists are slowly returning to Gorongosa.

21,027

SNARES AND TRAPS CONFISCATED

Snares and steel-jaw traps remain the primary threat to lions. Some 1,700 snares and traps were also voluntarily surrendered in the collection effort beginning in 2015.

50

GIRLS' CLUBS

Serving 2,000 girls in the buffer zone, these before- and after-school programs teach important life skills that help girls stay in school and avoid child marriage.

617

LOCALS EMPLOYED

The project also supports 375 community health workers, 1,200 Girls' Club promoters and *madrinhas* (volunteer "godmothers"), and 5,000 small farmers.

Predators Returning

The year 2018 saw 30 new lion cubs, the first leopard sighting in a decade, and the reintroduction of a pack of African wild dogs. Some species of prey are overabundant due to low predator numbers. But recent lion-tracking data indicate that efforts to restore the balance are working.

Range

Sungwe lion pride

Flavia is an adult lion from the Sungwe Pride, collared in 2015. When the park first began tracking lions, a cluster of GPS points (showing reduced movement) usually indicated a snared lion. Now, with increased law enforcement, clusters more often reveal an encouraging situation: lionesses raising cubs.

Flavia

1. **April 20, 2015** The lioness is collared at the lion house.
2. **June 15, 2016** She gives birth to three cubs.
3. **April 20, 2018** She gives birth to four cubs and later adopts another from an older lioness.
4. **September 10, 2018** Flavia teaches her cubs how to kill a waterbuck.
5. **October 29, 2018** The African wild dogs come near her cubs; she chases them off.

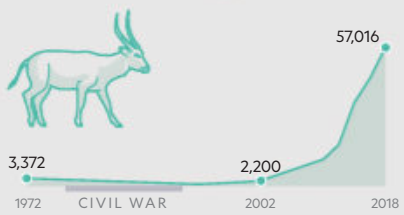
Range

African wild dogs

When they were brought to Gorongosa in April 2018, most of the wild dogs didn't know each other. To ensure they bonded together as a pack, the park kept them in an enclosure for two months.

Waterbuck

The park was once dominated by buffalo; now waterbuck are the most abundant herbivore, accounting for 63 percent of the park's animal biomass. With few predators and improved water access, the large antelope species is thriving along the park's lakes and rivers.



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Buffalo

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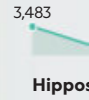


Hippos

A sepa Vundu also in than 50 first ti civil wa were m pos thr

Elepha

Most p killed f during 544 ele but the to 650, female were h

TURNING POINTS

STRIKING A BALANCE

The wildlife of Gorongosa National Park was decimated during Mozambique's 1977-1992 civil war and the desperate years that followed. Now Mozambican and international conservationists are bringing the park back to life by bolstering the animal population and improving human lives by opening schools, clinics, and promoting sustainable farming in nearby communities.

eping Count

orongosa Restoration Project cts biennial helicopter surveys pproximately 750-square-rea to track growing wildlife ers as animals are brought n South Africa and other of Mozambique.

Individuals counted during 2018 helicopter survey

250
100
10
1

90 1,021
2002 2018

s from other African were introduced ter Gorongosa's rs. Initially they ept in an enclosed ary. Once the first rew large enough, , the sanctuary were opened to buffalo roam.

Chitengo Camp

210 buffalo released between 2006 and 2011

160 546

s
rate flight down the zi and Urema Rivers, 2018, counted more 00 hippos for the me since before the ar. Back then, there hore than 3,000 hip- riving in the park.

5 hippos released in 2008

300 650

nts
ark elephants were or their ivory and meat the war. Last October ephants were counted, e true figure is closer as six collared s and their families iding in vegetation.

6 elephants released in 2008

opens

2016

14 African wild dogs reintroduced

2020

Long-term agreement with Carr Foundation renewed

BUFFER ZONE

MOUNT GORONGOSA
(GORONGOSA N.P.)
6,112 ft
1,863 m

Murombodzi waterfall

Coffee plantation

Vunduzi

Valley

Urema

PARK BOUNDARY

Nhandugue

Bunga Inselbergs

Plateau

Northern headquarters
(PROPOSED)

Vila Gorongosa

Vunduzi

Rift

GORONGOSA NATIONAL PARK

Báruè

Lake Urema

Mussicadzi

Community Education Center

Mussinhá

Camp Muzimu

Chitengo Camp

WILDLIFE SANCTUARY

E.O. Wilson Biodiversity Lab

Park entrance

Muanza

Mecombezi Ponte

Vinho

Púngoè

Urema

2018 SURVEY AREA
Enlarged at left

Great

Cheringoma Plateau

New Facilities
- Clinic
- School
- Well
- Agriculture project
- Ranger post

0 mi 8
0 km 8

AFRICA

MOZAMBIQUE

AREA ENLARGED

Zambezi

12

GORONGOSA N.P.

Proposed corridor

Muanza

MARROMEU NAT. RESERVE

INDIAN OCEAN

Buffer zone

Hunting reserve

0 mi 30
0 km 30

The park began managing Hunting Reserve 12 in 2017. By working with nearby communities, planners hope to create a wildlife corridor from Mount Gorongosa to the Indian Ocean.

POPULATION ESTIMATES BASED ON GROUND AND AERIAL SURVEY COUNTS.
RYAN T. WILLIAMS, NGM STAFF; JAMES CHESHIRE AND OLIVER UBERTI
SOURCES: PAOLA BOULEY, DOMINIQUE GONÇALVES, VASCO GALANTE, PIOTR NASKRECKI, AND MARC STALMANS, GORONGOSA NATIONAL PARK

Boston Technology, which presciently offered ways to connect telephone systems with computers. Another successful enterprise followed, and by 1998, not yet 40, Carr found himself on the receiving end of an $800 million deal. "My hobby was to read paperbacks that I could buy for five bucks," he told me during a conversation at Gorongosa. "It was more money than I needed."

He established the Carr Foundation, a philanthropic entity, before he knew for certain what its purpose would be. But the works of Edward O. Wilson had awakened in him a keen interest in conservation. At the same time, he was immersing himself in the study of human rights and its great prophets and advocates, including Nelson Mandela. These two lines of study converged later when Carr learned that Mandela, by then president of South Africa, was collaborating with his fellow president, just across the border in Mozambique, to create "peace parks"—trans-boundary national parks for the conservation of wildlife and the benefit of local people.

"President Chissano loved national parks," Carr said, and during Carr's first visit to the place, in 2004, "he invites me to restore Gorongosa."

Three years later, Carr signed a long-term agreement with the government. He would bring to the challenge not just his financial resources and management acumen but also a shared vision that Gorongosa could become a "human rights park." That meant generating tangible benefits for the local people around it—in health care, education, agronomy, economic development—as well as protecting its landscape, its waters, its biological diversity in all forms. The National Geographic Society also funds conservation and science in and around the park, as well as community development and women's education and empowerment projects.

ON A WET THURSDAY MORNING in April, nine little girls jumped rope beneath a sheltering tree in Mecombezi Ponte, a village about 20 miles from the park. They wore dark blue T-shirts with "Rapariga do Clube" (Club Girl) emblazoned on the back and a small round seal saying "Parque Nacional da Gorongosa" on the front. In a semicircle around the girls stood 10 *madrinhas,* or volunteer "godmothers," giving their time and quiet vigilance to help protect these young girls from the jeopardies they face: forced early marriage, frequent pregnancies, bad health, and truncated education.

The Girls' Club of Mecombezi Ponte is one of 50 clubs organized and sponsored by the park to augment daily school sessions for some 2,000 girls throughout the buffer zone. Monday, Wednesday, and Friday focus on literacy. Tuesday's agenda is health and reproduction. Thursdays, as Carr and I saw, are devoted to play. The women clapped and sang while the girls gleefully took turns in the twirling rope. Carr, sporting a T-shirt, shorts, and a two-day growth of beard, joined the line of girls and gamely tried to jump rope. The girls were better.

Carr regards the Girls' Clubs as a critical part of the Gorongosa National Park resurrection. Deterring men from hunting the park's wildlife—through alternative livelihoods as well as ranger enforcement—is important but insufficient. Women are the fulcrum. If the human population in the buffer zone continues to grow unabated, by way of early marriage of girls and large families, no effort within the park boundaries will be sufficient to protect its landscape and fauna. "But if girls are in school and women have opportunities," Carr said, "then they will have two-child families." It's not an imposed solution. It's part of a phenomenon resulting from women's empowerment. "This is where human development and conservation merge," he added. "Rights for women and children, poverty alleviation—is what Africa needs to save its national parks."

Before departing, we witnessed a small ceremony. A sixth grader named Helena Francisco Tequesse stepped forward and, from a laminated card, read a declaration of 10 rights and 10 duties of children. "Children have the right to be fed and a duty not to waste food," she read. "Children have the right to live in a healthy environment and a duty to care for the environment."

"This is really exciting," Carr said. "When I came here, the percentage of women in the buffer zone who could read—zero." He asked the girls to say what they wanted to be when they grew up. Each stepped into the dirt circle, said her name, and answered with poise: a nurse, a midwife, a teacher, another nurse, a police officer. By now, with the rain finished and the morning turned sunny, the group had grown to about 30 girls and madrinhas. As we left, they resumed clapping and singing and dancing.

THOUGH IT LIES outside the park's original boundary, Mount Gorongosa is an indispensable part of the Gorongosa ecosystem. The mountain

not only captures rainfall and delivers it to the park's floodplain, it also adds a diversity of altitude, climate, soil, vegetation, and wildlife to the greater Gorongosa whole. In 1969 a South African ecologist named Ken Tinley proposed that the mountain, as well as the plateau and coastal habitats stretching eastward from the park border, also richly various, be combined into a single integrated management area.

Tinley's idea has taken hold as the "mountain to mangroves" vision of Gorongosa. In 2010 the highlands of Mount Gorongosa (above 700 meters, or about 3,000 feet) became part of the park. That mountaintop encompasses the source of the Vunduzi as well as some remote forest (still held by rebels, despite the most recent cease-fire), but across the lower elevations local people continued cutting, burning, and farming. They had little choice.

felled by RENAMO soldiers to block the road and thwart government vehicles, had been pulled aside and left rotting. Slightly higher, we reached the hospitable elevation for coffee.

"This mountain has got a fantastic environment," Haarhoff said. Good humidity, temperatures are cool and don't fluctuate greatly, and there's no frost. "You try to do this in Zimbabwe, and your coffee would be dead by now."

Growing coffee beans and restoring forest in an on-again, off-again war zone is still daunting. But the local farmers embrace the enterprise—as evidenced by the women who came out at night and watered the young coffee plants even during the renewed fighting in 2014. Those plants survived and now flourish, along with many more.

We parked the Jeep and proceeded by foot, crossing a small river on stepping-stones and inspecting a tree-shaded nursery of 260,000

THE PARK NOW EMPLOYS 180 PEOPLE

IN ITS COFFEE PROJECT, WHICH AIMS TO TEACH RESIDENTS HOW TO RAISE A CASH CROP THAT WILL PROVIDE A STABLE INCOME.

Soon afterward, the park's forestry manager—a Mozambican named Pedro Muagura—made a suggestion at a meeting: Why not grow coffee on mountainside plots that have already been deforested? It could be shade-grown, beneath replanted native trees, giving local people a bit of income as well as restoring the forest. Muagura fought off initial skepticism and is now the warden of the park. And his coffee idea, despite a flare-up of the war in 2014-16, when government forces advanced up the mountain to attack the rebel holdout, is blooming nicely.

Quentin Haarhoff, the park's chief coffee expert, farmed coffee in Zimbabwe—until the day, he told me, when President Robert Mugabe made white farmers unwelcome, and he left at the point of a Kalashnikov rifle. We were driving up to the coffee project area on a steep two-track that climbs the massif's southern slope, passing fields of sorghum and corn, a few houses and huts, a patch of pineapples. Big hardwood trees,

coffee starts, each one growing from a scoop of soil in a potlike plastic sleeve. Farther upslope, we moved amid producing trees, bush-size and healthy, planted in cross-slope rows and shaded by acacias and other trees. The park now employs 180 people on this work, Haarhoff explained, as a demonstration project. The plan is to show how it's done—coffee plants, shaded by native trees, mulched with compost, weeded by hand, with vegetables, fruits, and legumes as secondary crops between the rows—and then to supply training, tools, coffee starts, and seeds, and to offer a good price for the harvested coffee, which is bought by Produtos Naturais, a natural-products enterprise within the park's sustainable finance division.

Produtos Naturais processes the coffee at its new factory nearby and markets the roasted beans to Mozambican wholesalers. The coffee and other premium cash crops (such as cashews) will give local people better livelihoods

After a few years of acclimation and breeding in a fenced sanctuary, zebras load into a trailer to travel to a release site in the park, where they'll face the freedom and peril of the wild. The park's population was almost eliminated during the war.

One of two male lions known as the Senators lies tranquilized for a change of collar, while ranger Cubalua Joaquim watches for elephants and other lions. Vet-in-training Mercia Angela (with antenna) and Victoria Grant, a U.S. researcher, have administered vaccinations.

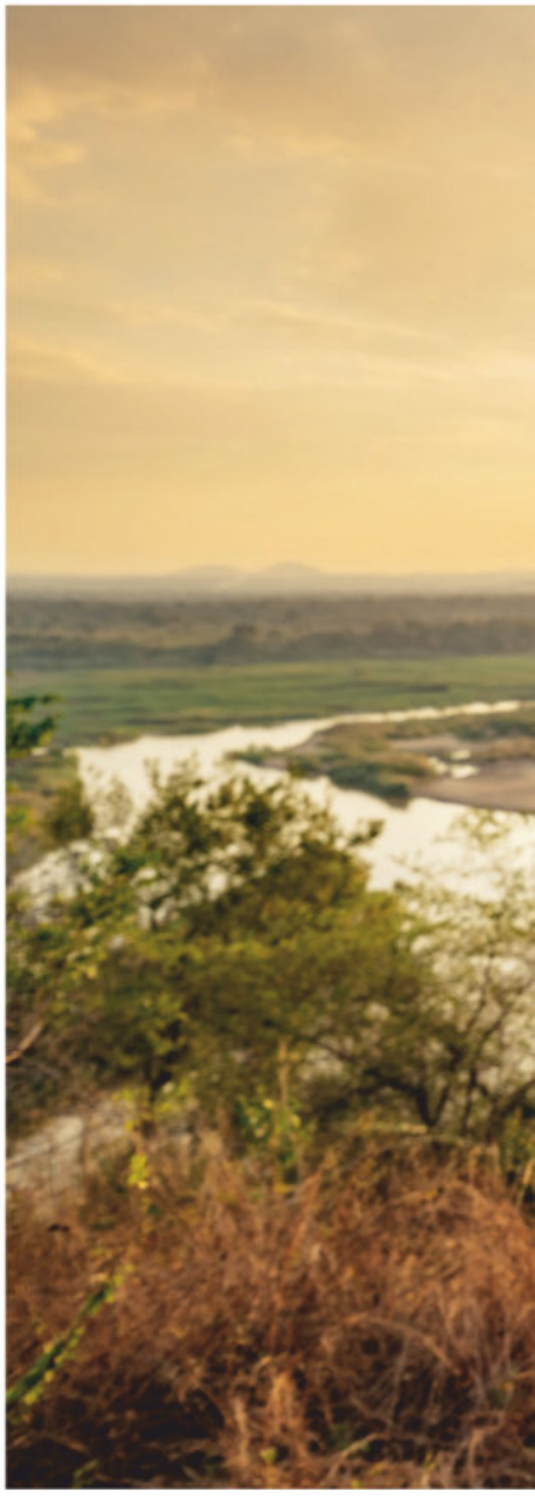
and wean farmers away from slash-and-burn corn, thereby not just protecting what's left of the mountain forest but also reforesting areas that have been cut. "I'm not a scientist," said Haarhoff, "but the birds have come back; the bees have come back. You can just see nature breathing a sigh of relief."

NATURE IS RESILIENT, but its sighs of relief, its trends of recovery and resurgence, require more than reforestation of mountainsides and protections against poaching. A pack of African wild dogs (a native predator, lost during the war) was released into the park in 2018, after weeks of acclimation in a large pen. A small herd of zebras also trotted cautiously from their corral into a trailer and then into the wild. And a solitary leopard was spotted.

Black rhinos once roamed Gorongosa as well, but that difficult reintroduction, with high risks of attracting commercial poachers, will have to wait. Full recovery takes time and space. The time dimension is recognized in a long-term agreement between Carr's group and the government, renewed in 2018 for 25 years. Of course, even 25 years is just a beginning in ecological terms.

The significance of space—bigger protected areas generally embrace more diversity and greater ecological wholeness—helps explain why Carr and his colleagues, including partners within the Mozambican government, favor further enlarging Gorongosa in line with that early mountain-to-mangroves model. They envision a greater Gorongosa ecosystem—all of it protected or sustainably managed, encompassing successful farmers and other local enterprises—connecting Mount Gorongosa in the west, the park in the southern Rift Valley, large blocks of hardwood forest on the Cheringoma Plateau just east of the valley, and the unique coastal woodlands and swamps on the south side of the Zambezi River Delta. The coastal piece of that puzzle already enjoys some protection as Marromeu National Reserve, a soggy and roadless wilderness rich with African buffalo and birds.

On another fine morning, Carr and I lifted off in the JetRanger with Marc Stalmans, director of the park's science department, and headed east toward Marromeu, passing low over savanna, then palm forest, then the thicker forest of the plateau. Flying over this landscape in 50 years, Carr said, Dominique Gonçalves or someone else of her generation would see wildlife in huge round numbers: 10,000 elephants, 1,000 lions. As for buffalo, maybe 50,000.



Dominique Gonçalves, a young Mozambican ecologist and National Geographic fellow, runs Gorongosa's elephant program. The park's scientists and managers are multinational, but more and more Mozambicans are filling leadership roles. The place is evolving toward the guiding vision of a "human rights park," serving nature and people, overseen by Mozambicans, shared with the world.

"Difficult but doable," Carr added. "I like the idea that it's just on the edge of possible."

"Difficult" is an understatement. The latest aerial count of wildlife in the park, in October 2018, revealed continuing increases for many species—buffalo up, kudu up, impala way up. In addition to the reintroduction of African wild dogs, populations of zebras, wildebeests, and eland have grown. Patrol sweeps by rangers—261 of them, including a small but growing number of women—have kept poaching to a minimum. The latest counts show that Carr's goals are a long way off, but if the edge of the possible can ever be realized, it will be here, in Gorongosa National Park.

Pingo lowered the helicopter onto the beach at Marromeu, and during a brief stop there, he and Stalmans and I talked about African buffalo while Carr wandered off. Buffalo need grass, water, and occasionally shade, Stalmans said, but not much else. Before the civil war, there were 55,000 here in the Marromeu National Reserve. After the war, just 2,000. And those 2,000 buffalo survived only because the soggy coastal terrain made them so hard to hunt.

By this time, we noticed that Carr had ditched his shoes and waded far out into the surf, nudging at limits, as he often does, like a little kid. Returning, he started to conjure a beach lodge, right at this site, bringing tourists to enjoy the coast and the wildlife, plus a marine research station, together anchoring the great sweep of variegated ecosystem: the mountain, the valley, the lake, the plateau, the coastal wetlands, the mangroves, the beach.

"Put it together," Carr enthused, "and you've got something extraordinary."

We climbed back into the helicopter. Whirling off, we passed above a sizable herd of buffalo, dark and sleek and each with a couple of egrets, blazing white, perched on its back. The birds rose up and away, spooked by our noise, like a flock of guardian angels returning to base. □

David Quammen's latest book is *The Tangled Tree: A Radical New History of Life*. **Charlie Hamilton James** specializes in wildlife and conservation issues, particularly in Africa and South America.

INTO THE FIRE

EACH SUMMER, ELITE TEAMS KNOWN AS SMOKEJUMPERS PARACHUTE INTO ALASKA'S BACKCOUNTRY IN A DANGEROUS RACE TO FIGHT REMOTE FIRES.

BY **MARK JENKINS**
PHOTOGRAPHS BY
MARK THIESSEN

PREVIOUS PHOTO

Matt Oakleaf, camera mounted on his gear bag, drops behind the rest of his team to a landing site near smoldering boreal forest. Jumpers can put on 100 pounds of gear and get on a plane in minutes. Their mission: extinguish fires before they rage out of control.

THIS PHOTO

A Fire Boss plane dumps water to aid a ground crew fighting Fire 320 in the Brooks Range in June 2016. The single-engine plane is fitted with pontoons that can slurp up and disgorge 800 gallons every few minutes—here from nearby Iniakuk Lake.

Derek Patton, left, and Spencer Robertson pause after knocking down Fire 323, ignited by a lightning strike near Bettles, Alaska. About 10 out of more than a hundred applicants are selected for Alaska smokejumper training each year. Candidates must already have wildland firefighting experience.

THE SUN IS STILL HIGH IN THE ALASKAN SUMMER SKY

WHEN THE CALL COMES IN AT 9:47 P.M.

SIRENS WAIL, AND EIGHT SMOKEJUMPERS race to the suit-up racks. Already in logger's boots, dark green pants, and bright yellow shirts, each man practically leaps into his Kevlar jumpsuit.

"First load to the box!" a voice blares over the intercom. Itchy, Bloemker, O'Brien, Dibert, Swisher, Koby, Swan, Karp, and Cramer are the men at the top of the jump list. All evening they've mostly been hanging around the operations desk at their base at Fort Wainwright, cracking jokes and razzing each other, anxiously and excitedly waiting for their turn to leap out of a plane to fight a backcountry forest fire.

Now they have exactly two minutes to suit up and be on the plane. It's a much practiced routine: Their hands fly nimbly around their bodies, strapping on kneepads and shin guards, zipping into jumpsuits, and buckling into heavy nylon harnesses. The jumpsuits are prepacked with gear—a cargo pocket on one pant leg is stuffed with a solar panel and raincoat. The pocket on the other leg holds energy bars and a 150-foot rope, plus a rappel device in case of a treetop landing. An oversize butt pouch contains a tent and a stuff sack for the parachute.

Other smokejumpers quickly surround them, helping the men put on their main parachutes and reserve chutes. Then each man grabs his jump helmet—fitted with a cage-like mask to protect his face during a descent through branches—and his personal gear bag, which holds a liter of water, leather gloves, hard hat, flares for lighting backfires, knife, compass, radio, and special aluminum sack that serves as a last-resort fire shelter.

Two minutes after the siren, they are waddling onto the tarmac, each laden with nearly a hundred pounds of equipment and supplies. Fully dressed, they appear awkwardly overstuffed, but every man carries a carefully curated, time-tested kit of the essential items a smokejumper needs to fight and survive a fire in some of the world's most remote and rugged forests.

Photographed by team member Mike McMillan, one of the crew aims for a landing near the tail of the fire—where it started close to a group of cottages. The billowing smoke column signals a rapidly spreading "gobbler," a wildfire that's "off to the races," McMillan says.

Incident commander Ty Humphrey communicates with a pilot who has dropped a pallet of cargo near a fire. Crew members free the chute from the tree where the load landed.

Smokejumpers use beaters—strips of hard rubber on flexible shafts—to pound burning moss and tussock grass into the moss below, damp from melted permafrost. Such swampy coniferous forest, or taiga, is typical of high northern latitudes.

The twin turbines of a Dornier 228 cargo plane roar to life as the bulging khaki figures totter single file up through the side door and into the plane's belly, which is packed with pallets of firefighting equipment that will be dropped with them. The plane lifts off, and the dispatcher radios the coordinates of the fire. Time en route: one hour 28 minutes.

It's too loud for talk, so the men sit silently, each alone with his thoughts behind his face mask. They don't know where they're going or how long they'll be gone. They don't know how big the fire is or how dangerous the winds will be. They know only that they're going into battle with one of nature's most savage and unpredictable forces.

Five minutes out, the spotter, Bill Cramer, raises his hand, wordlessly calling for a "pin check." Each man executes a final multipoint equipment check of his jump partner.

They are flying above the Arctic Circle on the southern edge of the Brooks Range when they spot a plume of smoke rising from the dark green carpet of forest, the result of a lightning strike. Cramer opens the jump door and leans out into the slipstream for an assessment: "Fire number 320, 15 acres, 70 percent active, burning black spruce with caribou lichen understory, 11 structures on north and west shores of Iniakuk Lake, 1.5 miles west."

The pilot circles at 1,500 feet. Cramer identifies the jump site and drops three crepe-paper

streamers. Three bright stripes—yellow, blue, and orange—unfurl in the sky, allowing him to assess wind speed and direction.

"Get in the door," Cramer shouts. The first man on the jump list, Jeff McPhetridge, 49, known as Itchy, dangles his feet out of the plane. "Get ready!" Cramer shouts, and a moment later slaps him on the shoulder. McPhetridge hurls himself from the plane. Three smokejumpers follow. On the second pass, the remaining four men fall into the sky. Their red, white, and blue chutes circle over the flaming forest like tiny moths riding the drafts above a campfire, each man deftly maneuvering his wing in the wind.

One by one, the smokejumpers fly toward the smoke.

THE EIGHT MEN DESCENDING from the sky can trace their professional lineage to a lightning bolt that hit a tree just east of Yellowstone National Park in August of 1937. The strike ignited a small fire that began crawling its way through the forest and eventually grew into the infamous Blackwater Fire, killing 15 firefighters and consuming 1,700 acres. A U.S. Forest Service investigation concluded that the only way to avoid such tragedies was for firefighters to attack backcountry fires when they are still small.

In the 1930s, the Forest Service began testing the viability of parachuting small teams into remote areas, and on July 12, 1940, the first smokejumpers were deployed onto the Marten Creek Fire in Idaho's Nez Perce National Forest. Over the next several decades, the Forest Service created seven smokejumper bases in the lower 48, and the Bureau of Land Management established two, including the one in Alaska. Today roughly 450 active smokejumpers are dispatched to wildland fires from these bases.

"Those early years proved that getting men on a fire when it was the size of your living room, rather than thousands of acres, saved money, forests, lives, and private property," says Chuck Sheley, a retired jumper and vice president of the National Smokejumper Association. "The same principle still applies today."

Over time, debate has arisen over the need for smokejumpers in the lower 48 as development has spread into previously remote areas. Now 90 percent of fires start within a half mile of a road, and most can be accessed by vehicles. But in the Alaskan interior—a region roughly the size of Colorado, Wyoming, and Montana combined—the vast majority of the land is accessible only by aircraft. Many remote fires are allowed to burn, but when a fire threatens lives and property, smokejumpers remain the frontline troops.

Alaska smokejumper training is among the most demanding in the world. Of the up to 200 people who apply each year, roughly 10 are selected for rookie training. The most competitive applicants have five to 10 years of wildland firefighting experience and can do 60 sit-ups, 35 push-ups, 10 pull-ups, run 1.5 miles in nine minutes 30 seconds or three miles in less than 22 minutes 30 seconds, and carry a 110-pound pack for three miles in less than 55 minutes. Each smokejumper must pass a version of this test annually to keep his or her job. (Currently all 64 Alaska smokejumpers are men, though

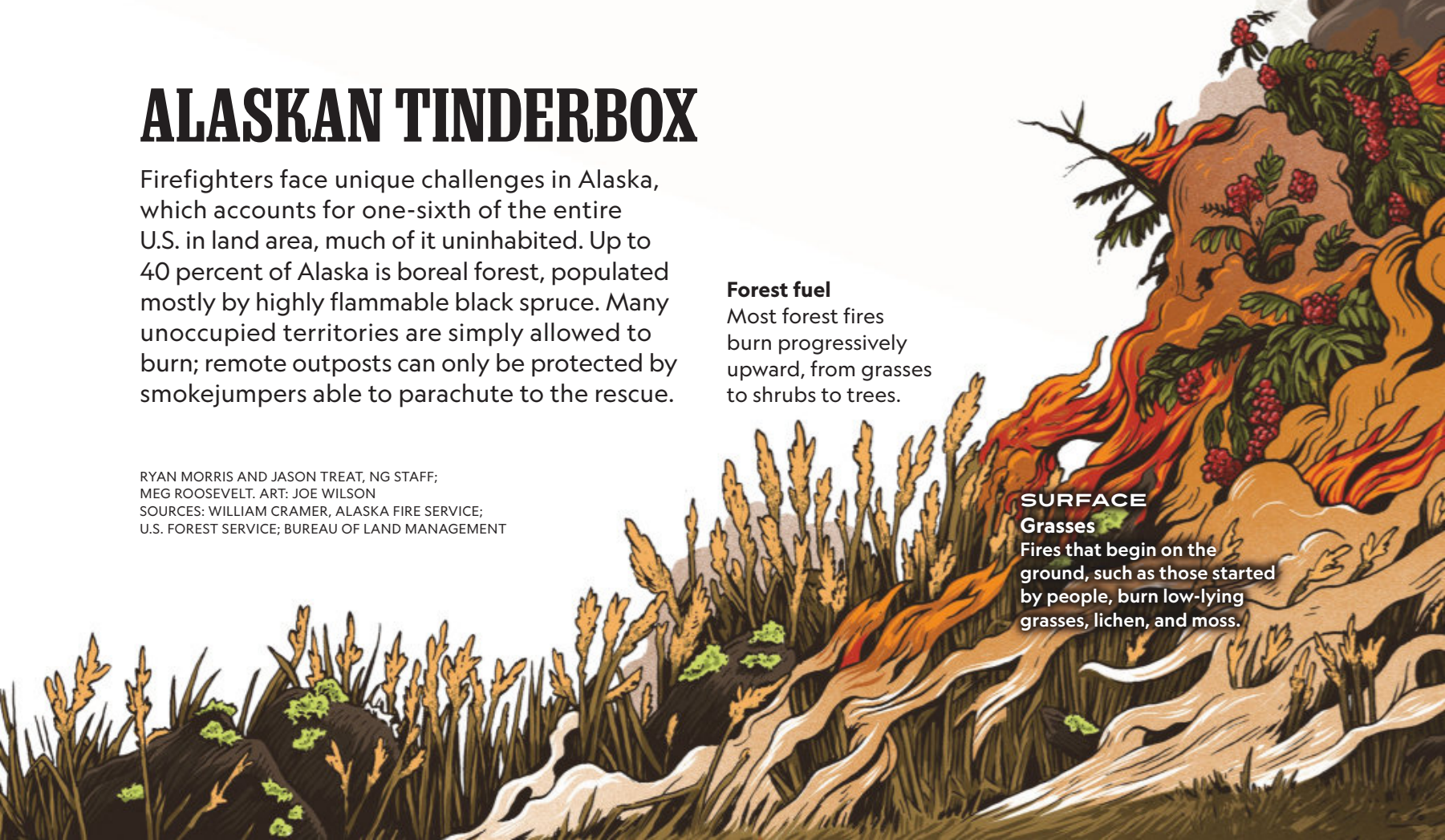
ALASKAN TINDERBOX

Firefighters face unique challenges in Alaska, which accounts for one-sixth of the entire U.S. in land area, much of it uninhabited. Up to 40 percent of Alaska is boreal forest, populated mostly by highly flammable black spruce. Many unoccupied territories are simply allowed to burn; remote outposts can only be protected by smokejumpers able to parachute to the rescue.

Attack and protect
About five dozen Alaskan smokejumpers divide their workload into three tasks: initial attack to contain early fires, protection of specific properties, and fighting larger fires.

Forest fuel
Most forest fires burn progressively upward, from grasses to shrubs to trees.

RYAN MORRIS AND JASON TREAT, NG STAFF;
MEG ROOSEVELT. ART: JOE WILSON
SOURCES: WILLIAM CRAMER, ALASKA FIRE SERVICE;
U.S. FOREST SERVICE; BUREAU OF LAND MANAGEMENT



over the years there have been seven women.)

"We only choose people who can perform under stress," says Robert Yeager, a former rookie trainer. "People who can control their nerves, their anxiety, and their adrenaline, people willing to accept life-or-death challenges."

Those accepted to the five-week training course already know how to fight fires, but they have to learn advanced parachute skills—how to quickly and accurately calibrate and account for numerous variables that constantly change: the wind, terrain, the state of the parachute, the landing zone. Rookies make at least 20 practice jumps, which are filmed and critiqued. Forty percent of the trainees don't make the cut.

But those who pass this crucible become members of an elite fraternity that includes Willi Unsoeld, one of the first Americans to summit Mount Everest; Stuart Roosa, the Apollo 14 command module pilot; Ken Sisler, an intelligence officer killed in Vietnam who was awarded the Medal of Honor; and Deanne Shulman, who in 1981 became the first woman to join the ranks.

THE SMOKEJUMPERS LAND less than 50 yards from the blaze now labeled Fire 320, tumbling onto their hips to absorb the impact. Within minutes they have packed up their parachutes. The pallets with firefighting equipment—chainsaws, shovels, beaters, Pulaskis (combination ax-adze tools)—are dropping into the landing zone. The men barely have time to break open the boxes before the wind shifts.

"Suddenly the wind was coming out of the south, rather than the north," McPhetridge, the designated incident commander, tells me later. "We were concerned the fire might flank us."

The men don't have time to gather the cargo chutes. Instead they go straight to the fire. Flames are shooting up spruce trees and igniting the brittle caribou moss. Smoke is pouring through the forest. The men begin pounding the edge of the fire with their beaters—poles with thick rubber blades on the ends—but it has been a dry summer, and the caribou moss is a six-inch bed of prime tinder. They knock it down, but the flames pop right back up.

"It wasn't going to go out without water," McPhetridge says. The men run to a nearby creek and fill up four five-gallon "piss bags" using their hard hats. Evan Karp, 36, a hulk of a jumper with a thick, untamed beard, sets up a water pump and begins laying hose while the

rest of the men race back to the fire.

McPhetridge gives no commands or orders. "Everybody knew exactly what to do," he says later. "That's the beauty of the unit."

While one jumper operates the water pump, filling and refilling the bladders, four men attack the left flank and three attack the right flank. The men move along the edge of the fire, pounding the flames, spraying water, choking on smoke.

The jumpers dig trenches, cut trees, and empty and refill the bladders without stopping. By 3 a.m. the next day, after several hours of backbreaking work, they've completed the fire perimeter. With blackened hands and faces, the men crawl into their sleeping bags for a few hours of sleep. They're back on the fire line at 7 a.m. Some use chainsaws to cut down green trees to expand the fire line around the smoldering black edge of the blaze, others are digging with their Pulaskis.

The initial attack is over, and McPhetridge walks the perimeter of the fire. It's only 33 acres, a tiny fire compared with the huge conflagrations that make headlines in the lower 48. But left unchecked, it could've burned thousands of acres, perhaps tens of thousands. He calls the fire dispatcher with an update and is told headquarters is pulling his team out. A crew of firefighters drawn from local Alaska native communities will be helicoptered in for the final mop-up duty. They will go over every square yard of the "black," digging and dousing, making sure the fire is completely out.

Just before 9 p.m. the day after they parachuted in, the eight smokejumpers are helicoptered 50 miles to Bettles, a tiny village consisting of a couple lodges and a dirt airstrip deep in the Alaskan interior. Mission accomplished.

Or so they think.

TWO BAD THINGS HAPPEN after the smokejumpers are pulled off Fire 320. First, the equipment for the Alaska native crew is delayed in Fairbanks, so they never make it to the fire scene to do the mop-up. Second, winds sweep down from the north and breathe new life on the embers. The fire starts to blow up, and the afternoon after leaving the area, the smokejumpers helicopter back in. By the time they're on the ground midafternoon, the fire has spread across 150 acres, and they immediately call in reinforcements. Another load of eight smokejumpers drops in, and together the 16 men begin to cut a line along the reborn fire's left flank, using the

Smokejumpers each carry 100 or so pounds of time-tested gear needed to fight and survive a remote fire.

1. Helmet with cage mask protects the jumper's face from tree branches.

2. Smokejumpers often make their own jumpsuits, heavily padded and with plenty of pockets to hold gear. A reserve chute is worn on the chest. Kneepads fit inside the suit. Heavy leather gloves and boots offer extra protection.

3. Radio allows communication among smokejumpers and planes.

4. Personal gear bag holds supplies, including water, flares, compass, GPS, food, rain gear, emergency fire shelter, headlamp, and insect spray.

5. Parachute container holds, in separate compartments, a drogue chute that releases first to stabilize the jumper and a main chute that's deployed by pulling the green rip cord.

6. Let-down bag contains rope so a jumper who lands in a tree can get to the ground.

7. Large pack-out bag carries everything here.

8. Beater is used to pound flames into moist layer of moss beneath the burning surface.

9. Burlap bag can be soaked and filled with damp moss to smother flames.

10. Pulaski is used for clearing smoldering brush and small trees.

After smoldering through the winter, the Big Mud Fire burst to life 55 miles southwest of Tanana in the hot, dry, windy conditions of late spring in 2016. Smokejumpers were sent to protect a single cabin beside a river on the fire's flank. The fire ultimately covered 45,000 acres.

Iniakuk River to hold the right flank. But because of the dry conditions and abundance of the brittle caribou moss, the blaze can't be beaten into submission. Without lots of water, it won't go out. The smokejumpers call in the Fire Bosses—crop dusting–style planes equipped to carry 800 gallons—to bomb the flames. They zoom in low and release their loads of water, then circle back to Iniakuk Lake, glide over its turquoise surface at 80 miles per hour, scoop up another 800 gallons, and return to drop it on the fire.

Still, the flames persist. The fire is now burning so hot that it reignites right after a drenching. Fanned by the winds, it gains momentum, flowing like molten lava into green timber. Bigger scooper planes are called in, CL-415s, which can release 1,600 gallons at a time, along with a helicopter with a huge water bucket hanging from a long line. While multiple aircraft fly successive water-bombing missions, the men on the ground race to cut a defensible fire line north through the forest—chainsawing trees, mowing down the underbrush, pounding out flames. By 10 p.m., seven hours after jumping in for the second time, they have tied the north end of the left flank into the curving Iniakuk River.

Around midnight the smokejumpers withdraw to a campsite near the fire. Their faces are blackened with ash, their eyes raw, their bodies battered. Each man wearily cooks his dinner over the campfire. They eat military MREs as well as cans of chili or string beans, tins of sardines, and loads of energy bars. But the night's specialty is Spam, slow-fried with fresh onions and peppers over scarlet coals.

The men swat mosquitoes and squint into the fire. Their clothes are caked with salt from sweat, but someone is always willing to tell a story. Like the time David Bloemker dislocated his shoulder. The season had ended in Alaska, and he was down in Montana parachuting on a fire in Kootenai National Forest.

"Then the wind just died and there was a log I hadn't seen in a bad spot," says Bloemker, 45, who's spent two decades as a smokejumper. "I flared but came in too hot. My toe caught on a tussock of bear grass. Smashed my shoulder and blew out my labrum. Had to hike to where a helicopter could land, maybe a couple of miles."

The men nod silently; most have already heard this tale. The stories serve as more than just entertainment—they're a way for smokejumpers to teach each other. The real-world lessons of fighting unpredictable fires in remote wilderness are too numerous to fit into a couple years of training. Freakish wind changes, embers of old fires that survive winter only to ignite in spring, parachute malfunctions, backup-parachute malfunctions, chainsaw mishaps, colleagues who never made it home from their last deployment—these and hundreds more are gleaned over long careers and passed on by exhausted firefighters around campfires such as this one.

Bloemker stands up, dumps the remains of his tin cup into the fire and adjusts the .44-caliber Smith & Wesson on his belt. The revolver prompts another story.

"We were deep in the interior near Bear Lake, funny enough. We'd heard there was a habituated bear in the area, breaking into cabins. When we got off the fire and back to camp, we could tell a bear had messed with our gear. The next day the bear came back and tore into one of our tents. We started up a chainsaw and scared it away. That evening the bear came back again, but this time we couldn't scare him away. He started getting aggressive, stalking some of the guys through the trees. He made a false charge. Then he made a second false charge. On the third aggressive move I braced myself in the notch of a tree and shot him between the eyes."

The story is a reminder that fire isn't the only adversary in the backcountry. But by this time some of the grimy men are fast asleep.

THE SMOKEJUMPERS ARE BACK on Fire 320 at 7 a.m., but during the night the winds have shifted again. The fire has exploded to 600 acres. The flames are now throwing embers hundreds of feet into the air and across the river. It is quickly decided that the far side of the river is indefensible, so the men start cutting a line south to tie up the left flank. They toil for hours, breathing smoke, spitting ash, sweating through their filthy clothes.

But "Big Ernie," the smokejumpers' name for the fickle god of forest fires, has a twisted sense of humor. Just as they're getting close to anchoring the left flank to the river, winds sweep the fire south along the unprotected opposite bank, then shift to blow embers west back across the river, planting a new "spot fire" behind the men, one that threatens to surround them.

The smokejumpers must remain hypervigilant to such changes, McPhetridge says. "You can't control the winds. You can get killed."

The spot fire rapidly spreads in all directions

THE SMOKEJUMPERS ARE POUNDING FLAMES ALL ALONG THE BLACK AREAS. PLANES ROAR OVERHEAD, DROPPING WATER. THE MEN ARE DRENCHED.

through dry caribou moss. Most of the men shift southward in an attempt to circle the spot. Two men with chainsaws are cutting everything in sight along the edge of the flames. Some of the crew are dragging the unburned trunks into the green areas to deprive the fire of additional fuel. Others are pounding the flames along the black with beaters. The Fire Bosses roar overhead every four minutes, dropping water. The men step back but are still drenched.

After hours of frantic work, the northern and western edges of the new spot fire are almost under control, but the flames are now howling southward, borne by a northern wind. The 16 smokejumpers just can't get ahead of the fire. Their only option is to pull out before it cuts off their escape route.

The next day the fire will grow to 1,500 acres and the smokejumpers are forced to retrench, moving from offense to defense. One of the veteran jumpers laments his crew being pulled off the fire before it was completely extinguished. "We'd caught it at 33 acres," he says. Smokejumpers ruefully call this "catch and release."

Their only goal now is to protect the few cabins and a lodge on Iniakuk Lake. Using Zodiac watercraft, they shuttle fire hoses, water pumps, and sprinklers to each structure on the lake. The pumps are set in the lake and the sprinklers set to protect the roofs of the cabins.

Jeff Poor owns the cabin closest to the fire. A scraggly old trapper who was once from the East Coast but "went as far away as I could possibly get," he built his cabin by hand in 1976. "More'n happy to see these smokejumpers!" says Poor, who sells his pelts—wolf, marten, lynx—to Russian buyers. "Always happy to have the help."

Pat Gaedeke, who with her husband built the lodge at the end of the lake in 1974, is the one who initially called in the fire. She is beside herself with joy. "I can't believe all the resources they're using to help us," she says.

Eventually, after dozens of sprinklers and thousands of feet of hose are deployed, each structure is protected inside a half circle of plumbing that can thoroughly soak the property and prevent it from burning.

The smokejumpers are back at their camp by 10 p.m. Exhausted, they sprawl around the campfire. Cans of peaches are passed around, and the men pull out the slippery halves with their blackened fingers. A chunk of cheese is making the rounds; each man lops off a portion with his knife. "Hey, you guys remember when ..." and someone starts a story.

THE EIGHT SMOKEJUMPERS on the initial attack ended up spending 16 days on the Iniakuk Lake fire before being relieved. The fire burned more than 36,000 acres, but all the structures in the area were saved. "The fire burned all summer and was still burning when we left in September," says Pat Gaedeke. "Mother Nature finally put it out when it began to snow." □

Mark Jenkins wrote about Myanmar's toughest mountain climb for the September 2015 issue. Staff photographer **Mark Thiessen** has covered firefighting around the world for nearly 25 years.

YOUR SHOT

KELLY BELL

PHOTOS FROM OUR COMMUNITY

WHO

Bell, a market research director in Washington, D.C.

WHERE

The annual Montgomery County Agricultural Fair in Gaithersburg, Maryland

WHAT

A Fujifilm X100F camera

Bell and her husband wanted to introduce their young daughter to the magic of a county fair. The toddler loved the games, the lights, and the food, including her first taste of a deep-fried Snickers, at the Montgomery County Agricultural Fair near Washington, D.C. Throughout the day, Bell returned to the same spot to photograph the rides and signs in different light. Before leaving the fair, she pointed her camera one last time at the silhouettes of people on swings—and captured this scene as one rider stretched out his arms.

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Pinyon Jay *(Gymnorhinus cyanocephalus)*
Size: Body length, 26 - 29 cm (10.2 - 11.4 inches); wingspan, approx. 46 cm (18.1 inches)
Weight: 99 - 111 g (3.5 - 3.9 oz) **Habitat:** Arid, high-elevation areas of western North America
Surviving number: Unknown; declining rapidly

Photographed by Marie Read

WILDLIFE AS CANON SEES IT

Social networker. As a member of a large permanent flock, the pinyon jay applies exceptional social cognition and flexibility to its interactions. It uses at least 15 distinct calls to communicate and mediate relationships. A cooperative breeder, this jay maintains pair bonds over multiple breeding seasons. Year after year, it has acted as a vital seed disperser, but its primary habitat of pinyon-juniper woodlands is threatened by agriculture and herbicides. Is its active social life now nearing an end?

As Canon sees it, images have the power to raise awareness of the threats facing endangered species and the natural environment, helping us make the world a better place.

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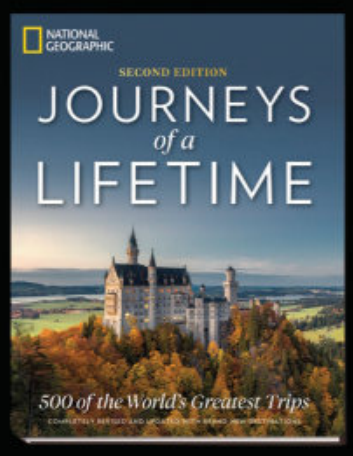

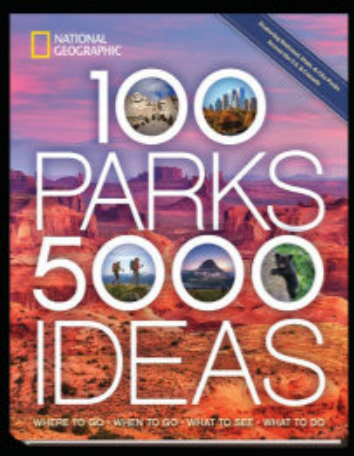

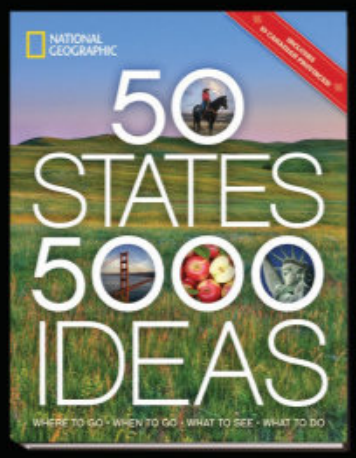

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